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ACCOUNT
O F
Animal Secretion,
The Quantity of Blood
In the Humane Body,
And
Muscular Motion.

By *James Keill*, M. D.

Profecto verisimile est, & Hippocratem & Erasistratum, & quicumque alii, non contenti Febres & Ulcera agitare, rerum quoque naturam ex aliqua parte scrutati sunt, non ideo quidem Medicos fuisse, verum ideo quoque majores Medicos exstitisse. Cels. in Præf.

L O N D O N,
Printed for GEORGE STRAHAN at the Golden Ball against the Royal Exchange.
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THE PREFACE.

D*iseases being purely Disorders of the Animal Oeconomy, whatsoever can add any new Light to our Knowledge of this, must necessarily clear the Nature of those, establish the Practice of Physick upon a surer Foundation, and enable Physicians to make truer and more certain Judgments in most Cases.*

The Animal Body is now known to be a pure Machine, and many of its Actions and Motions are demonstrated to be the necessary Consequences of its Structure. The Manner of Vision is shown in Opticks. Borelli has given us the Mechanism of the Bones and Muscles for the moving of

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the Joints. And since the Discovery of the Circulation of the Blood by the famous Dr. Harvey, many useful Propositions concerning its Motion and Velocity have been determined by Bellini. Dr. Pitcairne has explained the mechanical Structure of the Lungs, shewn us the reason of the different Passages of the Blood; thro' the Heart of the Fœtus, the necessity of breathing after Birth, and how the ante-natalitil Ducts are stopp'd by breathing: He has likewise demonstratively explain'd the Symptoms of the Diseases of the Eyes, and demonstrated the circular Figure of the Orifices of the Glands. Dr. Freind has wrote in a mechanical way upon the Menses; Dr. Cheyne upon Fevers; and Dr. Mead of Poisons, and all of them have handled these Subjects more rationally than ever any did before them. In the follow-

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following Sheets is contained a Calculation of the Force of the Air upon the Blood in Breathing, of the Quantity of Blood in the Human Body, of its absolute Velocity in the Aorta. The use of the Spleen and Vena Porta is now no longer a Mystery; and many Phœnomena of the Animal Body which the Ages past thought inexplicable, have now by several been made the Subjects of Geometrical Demonstration. That many Things still remain undiscovered, is not, that of their own Nature they are less capable of Demonstration; but that the Data are not sufficient, we are not yet fully apprised of all the Circumstances, which conduce to produce such Phœnomena. If some things which to former Ages have appeared unaccountable, are now as clear and demonstrable as the Pressure of the Air, why should we not hope for a Discovery

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of the Things that are still hid from us ? If we endeavour after them, there is all the reason in the World to believe we shall have Success, if we consider the Progress that has already been made, notwithstanding the mechanical Philosophy as applied to Physick is still in its Infancy.

Now since the Animal Body is a pure Machine, and all its Actions from which Life and Health do flow are the necessary Consequences of its Oeconomy; must not all the Symptoms of Diseases be likewise the necessary Consequences of the Alteration of this Oeconomy ? And doe they not as necessarily flow from this Change, as the Actions by which Life and Health are continued did flow from the Oeconomy before the Change. If a Pendulum of such a length makes a Clock to goe exactly true; does not the Alteration of the Pendulum as necessarily
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cause it to go too fast or too slow ; and when all the rest of the Movement is known to be in good order , does not the quick or slow Motion of the Clock , as necessarily show the Fault of the Pendulum ? It is the same thing in the Animal Body , for the same reasoning holds good in all sort of Machines , whose Motions are the necessary Consequences of their Structures : nor is the Case in the least altered , that we have a Principle within us , not subject to the Laws of Motion ; for our Souls are not at all conscious of the inward Motions of the Body upon which Life and Health depend , and tho' it do's sometimes influence our Health , yet the Irregularities it produces in the Oeconomy are to be rectified the same way as if they had proceeded from other Causes . Therefore it demonstratively follows that the greater our Knowledge of the Animal

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Oeconomy is, the better the Nature of Diseases must be known.

It must indeed be confessed that this Method of improving the Art of Physick is full of Difficulty, but the Nature of things cannot be altered; if it is to be improved, it must be by a Knowledge in the Animal Oeconomy, there being no other Method but what does really and in effect depend upon that.

Some do pretend that the Art of curing Diseases, is only to be promoted by Experiments, by observing what Things are hurtful, what beneficial in Diseases, that the Study of Nature and the Knowledge of the Body is altogether superfluous, and of as little use, as it would be to a Sailor to know the Reason of the Tides, or how to explain the Phænomena of the Loadstone. But if we consider the Number of Diseases, their different

rent Species, different Appearances according to the almost infinite Variety of Constitutions of our Bodies, and the Air in which we live. If we reflect likewise on their various Complications, on the infinite Variety of Medicines, and the critical Times of using sometimes one and sometimes another, we may as well expect that a blind Man should shoot flying, or one that is deaf tune an Organ, as that any one without the Knowledge of the Animal Oeconomy should ever find out a Remedy for any one Distemper. The Art of curing did indeed at first rise from Experiments, and it cannot be denied that several good Remedies have been found out by chance, or rather by Divine appointment, as without doubt the Use of the Bark was by the Indians; whom we may reasonably suppose to have been ignorant of the Animal Oeconomy, but

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no Man can think this a good Method for improving of any Science : If indeed Experiments are directed, by a Knowledge in the Animal Oeconomy, something may be hoped for from such a Method, and the greater the Skill is by which the Experiments are directed, the greater will be the Probability of Success; because by that we can aim more directly and certainly at the Irregularities of the Oeconomy, and he that knows the Disease is more likely to cure than he that is wandring and dubious in his Mind, and uncertain what it is he ought to aim at. If he hits the Mark it is owing more to mere chance, than any good Skill. Experiments are the only Foundation upon which by a just reasoning we come at the Knowledge of any Phœnomenon of Nature. Thus only Anatomical Experiments, and Observations

ons upon the Structure of the Parts, Nature of the Blood, and Secretions, can enable us to understand the Phenomena of the Animal Body; without them the raising of Theories and Hypotheses is but building of Castles in the Air. The Theory indeed of any Art, which has already arrived at its highest Perfection, and which has all its Circumstances known, may perhaps be of as little use, as that of the Tides and Loadstone would be for sailing in the Channel : But either of these might be of great use to a Sailor taken out of his Knowledge to an unknown Part of the World. Physick has not as yet arrived at its greatest Perfection in the curing of any one Disease, we are still ignorant of more than we know, and the Circumstances of Diseases are infinitely various, and no general Rules whatsoever can be applied to
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particular Cases, without the Knowledge of the reason of the Rule, that is, without understanding the Animal Oeconomy, upon which all Rules of Physick are built.

But the Method of curing Diseases, by drawing Indications from the evident and conjunct Causes, has been always most approved by the best and Generality of Physicians. The Knowledge of these Causes is not to be attained by reason, but by a close and assiduous Observation of all the Appearances in the several Stages of a Distemper. The first that excelled in this Knowledge was the Divine Hippocrates, whose Delineations of Diseases are truly charming. In them one may discern a wonderful Attention to all even the minutest Operations of Nature, which produced a surprising Sagacity in judging of future Events. In this Method several

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ral of the Ancients have followed him, but none ever came so near to him, as the deservedly renowned Dr. Sydenham, and Dr. Morton, whose Histories of Diseases, for a full, exact and nice Enumeration, and Description of evident Causes, Signs and Symptomes, for a judicious distinguishing of the several Species of the same Diseases, and for just Prognosticks founded upon a careful Observation of the common Effects of such and such Apearances, have surpassed all Histories of the Modern Physicians.

This is the Knowledge which added to that of the Animal Oeconomy can only make a Physician, one skilled in Geometry may as well pretend to be a good Astronomer, without knowing the Motions and Revolutions of the Heavenly Bodies, as a Philosopher, or one skilled in the Animal Oeconomy,
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to be a Physician without the exact Knowledge of the Histories of Diseases. And as one ignorant of Geometry can make but a wretched Astronomer, so he can make no better a Physician that has not laid a good Foundation of the Animal Oeconomy. If we consider the Animal Body as a Machine, its Diseases, and all their Symptoms are only the irregular Motions of the Machine. Now suppose a Man ignorant of the Structure of a Clock or Watch, it is impossible he should ever be able to put it in right Order, tho' he had never so exact an History of its irregular Motions. So a Physician ignorant of the Animal Oeconomy, is ignorant of the Structure of the Machine he undertakes to regulate; and the best and exactest Histories of Diseases can never suggest to him any Indication of Cure. It is therefore the Ani-
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mal Oeconomy which alone can enable us by reasoning upon the Causes, Signs and Symptomes of Diseases, to find out their Natures, and to deduce true and just Indications of Cure.

If we examine the Method of curing any Distemper we shall find what I have said to be true. For Instance, do not all the Symptomes of the Jaundice show us that the Liver is obstructed? And do we not deduce this Obstruction by our Knowledge of the Animal Oeconomy? And does not this Obstruction indicate, Bleeding, Vomiting, Purging and Deobstruent Medicines, which are used in curing of this Disease? If we know the Nature of the Humour which causes the Obstruction, perhaps Remedies might be found to cure such Jaundice as are now found to be incurable: For different Substances require different Resolvents, as every one that

that is acquainted in Pharmacy and Chymistry knows. From the Symptoms of the Jaundice we justly draw the Indication for giving deobstruent Medicines, but what are the most proper Medicines of this kind, we know not; because we are ignorant of the Nature of the Obstruction. Our Indications therefore are true and just, so far as our Knowledge of the Animal Oeconomy reaches; but where that leaves us we only grope in the dark, and find out Remedies by Chance.

But this will be still more evident if we consider, there is no Disease, better known, or which has its most minute Circumstances better described than a Tertian Fever; yet because we are ignorant of the Nature of the Blood, which is this Seat of the Disease, its History does not help us to any Indication, which if answered
will

will work a Cure, but we are obliged to the ignorant Indians for our knowledge in curing this Disease. And here again to shew the Necessity of the Knowledge of the Animal Oeconomy, and how vain a thing Empiricism is, tho' a more noble Specifick than the Bark was never known; yet we are frequently forc'd, when Intermitting Fevers are complicated to call in to our Assistance the Knowledge of the Animal Oeconomy, and by Vomiting, Purging and other proper means, to render that Specifick useful which before was of no effect.

If the Animal Oeconomy were perfectly understood, and the Histories of Diseases exactly known, the right Method of curing each Disease might be evidently and certainly deduced; and therefore when the History of a Disease is exactly known, if the right Method of curing it cannot be deduced, it must be because the Animal

Oeconomy is not understood ; and from hence it follows that our Skill in curing of Diseases whose Histories are exactly known, (abstracting what we are obliged to Empiricks for) is always proportional to our Knowledge of the Animal Oeconomy.

The Animal Oeconomy is its self a considerable Part of natural Philosophy, and our Bodies are strongly influenced by Variety of Diets , and so many things from without, that indeed the whole study of Nature seems to be useful to him that would understand it. And every discovery in things that affect us , seems to be an Improvement of Physick. Some of the Ancients have indeed left us very judicious and accurate Histories of Diseases, but since the discovery of the Circulation of the Blood, and the late Improvement of natural Philosophy , our Reasonings upon these Histories, in order to find out the Seat and Nature
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of the Distemper and from them to deduce a right Method of curing, and the whole Practice of Physick by the Invention of many useful Remedies, is so much refined, that who ever should affirm the contrary, would seem to me neither to have read the Ancients nor to be acquainted with the Practice of the Moderns.

But notwithstanding the great Advantages Physick has received from natural Philosophy, it must be owned, that it has likewise received a very great detriment from the too common Method of philosophizing; that is by laying down of Principles not drawn from the Phœnomena of Nature, but uncertain Fictions of the Brain; such as are the first and second Elements of the Cartesians, which are purely Chymical, and have no Foundation in Nature; and yet their whole natural Philosophy depends upon them: Tho' their reasoning upon such fictitious

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tious Principles were just, yet no Phœnomenon of Nature demonstrating their Existence, the best that could be said of their Philosophy is, that for ought we know, it is meerly possible; but that Nature does actually work this way, can never be shown, till the truth of their Principles can be demonstrated. Most Theories of Diseases are built upon such Principles, and therefore we never can have any Certainty, or indeed so much as a Degree of Probability, that the Indications drawn from them are right, or such as if answered, would cure the Disease. If a Man may suppose any Principles which are not evidently false, he may at the too common loose way of reasoning, give a thousand Solutions of the Nature of every Distemper, all equally true, and all indicating different Methods of curing. Tho' such a Knowledge may satisfie the
Curiosity

Curiosity of a Philosopher, yet it can be no sufficient ground for establishing the Practice of Physick upon: For a Man to hazard his Life (and he ought to be more cautious of another's) upon the truth of an Hypothesis which is barely possible, is to run a greater Risque than he does, who ventures his Estate in a Lottery, where it is only possible, but not at all probable that he should be a Saver.

But this sort of Philosophy is not only useless, but it is also prejudicial to Physick; for Men being generally fond of the Productions of their own Brains have studied these more than they have done the Operations of Nature in the several periods of Diseases, and have not stuck to mould and frame Diseases to answer their Hypotheses; so that most of the late Histories of Diseases, are only Philosophical Romances, and contain no-
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thing of that diligent Observation of Nature which gained Hippocrates immortal Honour, and without which it is impossible that ever the Art of Physick should be improved.

But such is the Narrowness of the Humane Intellect, that few Men are fitted for various Studies, or even for the several Parts of the same Science. Many have been very nice and exact in making Astronomical Observations, that have had but a very moderate Skill in Geometry, and such as have excelled in this have been deficient in that. And Men either from a want of Integrity and a Sense of that Truth and Justice that is due to Mankind, or from a natural Fondness of their own Qualifications, and an Unwillingness to think any thing of which they are ignorant, necessary to the Science they profess, have generally recommended and extolled those Parts which they
best

best understood themselves, but bantered and decryed those they were less skilled in, tho' not less necessary and useful. Natural Philosophy and the Histories of Diseases must go hand in hand in the improving the Art of curing; it is not possible to make any use of the last without the Knowledge of the first. And I may venture to say, that there is no Man that practises, but who does it upon some Knowledge of the Animal Oeconomy, or some notions of his own which are more or less clear according to his Skill in natural Philosophy. And for the Truth of this, I appeal to Dr. Sydenham's own Writings, who by his philosophyzing has evidently shewn us the Necessity of that Science, he so much decryed, and so little understood. He was undoubtedly a great Man, and the World will always be obliged to him for his accurate Histories of Diseases, but

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there is no Man without Errors, and where one of his deserved Character falls into a Mistake, it does a great deal more hurt, than if hundreds of others of lesser Note had been guilty of the same.

The following Treatises contain a few Thoughts about some of the principal Parts of the Animal Oeconomy; It was the Consideration of the Use of the Vena Porta which gave me the first hint to think that the several Humours of the Body were formed by the Attraction of the Particles of the Blood; which when I had communicated to my Brother, he was pleased to see his Theorems of Attraction illustrated by so eminent an Instance, and sent me the Demonstration of the third Proposition.

The first that I know of who, to explain Secretion, thought it necessary to consider the state of the Blood at different distances from the Heart, was
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the ingenious Dr. Cockburn; and 'tho he was not then aware of this Principle of Attraction; yet he wisely foresaw that different Velocities of the Blood were requisite for secerning of different Fluids.

As the Learned Dr. Gregory has, shewn us, in the Preface to his Astronomy, that the Gravitation of the Heavenly Bodies towards one another was known to the Ancient Philosophers; so this Power by which the smal Particles of Matter attract one another was the Doctrine of Hippocrates, (a) whose whole Philosophy is built upon a certain Propension which some things have to one another, whereby they attract, retain and alter one another. Galen (b) does assert this Attraction to be

(a) Vide Mr. Le Clerc's Histoire de la Medicine.

(b) Præterea conspirabile & conflatile totum corpus esse, Naturamque omnia julte & artificiose peragere, facultatibus scilicet præditam, quibus singulæ particulæ convenientem sibi succum

be an universal Power in Matter and (c) compares it to the Power by which a Loadstone draws Iron. (d) Hippocrates explains the manner that purgative Medicines operate just as we have done. And Galen in his Treatise de Purgantium Medicamentorum Facultate, does bitterly inveigh against all those who in opposition to Hippocrates did assert that all purges, purged all Humours indifferently; and concludes that every purgative Medicine draws to its self its proper

ad se trahunt, attractum vero coalescere, accrescereque omnibus suis partibus faciant. cap. 12. lib. 1. de Natural. Facultat. Ostensum est a nobis in Commentariis de Potentiis Naturalibus, Naturam uniuscujusque particulæ, quatuor uti potentiis, attractiva proprii alimenti, & ejusdem retentiva. Comment. 1. Aphor. 22.

(c) Ergo ad quem modum trahatur in commune investigemus; quo porro alio, quam sicut a magnete lapide ferrum, qui scilicet talis qualitatibus trahendæ vim habet. Lib. 2 Cap. 7. de Natural. Facultat.

(d) Τὸ γὰρ φάρμακον ὁπόταν ἐσθθῇ ἐς τὸ σῶμα, πρῶτον πρὸς αἵμα, ὃ ἂν αὐτίκῃ καὶ φύσιν μάλιστα ἢ τὸ ἐν τῷ σῶματι ἐνεόντων. ἔπειτα δὲ καὶ τὰ ἄλλα ἔλκει τὸ καθαίρει.

Humour

Humour. And he strenuously maintains a Vis Attractrix in Nature against Epicurus, Asclepiades, Erasistratus, and others in his Book De Naturalibus Facultatibus. All which does sufficiently show that this Attraction of the small Particles of Matter is no Innovation in Philosophy.

The maner by which I do suppose the Glands do seperate the several Humours from the Blood, is much the same with that of Dr. Morland's published in the Philosophical Transactions. What I have said concerning the Quantity of Blood is sufficient to show how little reason common Opinions are sometimes grounded upon. And the Difficulty of the Subject, and the new Method of handling it, will I hope procure this short Essay a favourable Reception. The Theory of Muscular Motion does follow so naturally and easily from the Principle of Attraction, that one would be almost

most tempted to believe it the genuine Method of Nature. The Determination of the Vis Elastica was the Thought of the Learned John Bernoulli; but this way of demonstrating it was communicated to me by my Brother: I am too sensible of my own Inabilities to persue those Thoughts which I have only started, and I should be pleased if they were of any use to Men better qualified to make Discoveries in Nature.

Tho' any one with a moderate Skill in the Mathematicks may understand these Discourses, yet without that no one can judge of their Truth, and Usefulness in explaining the Animal Oeconomy.

E R R A T A.

PAge 10. line 20. read distance. p. 14. l. 11. r. describe the Hyperbola b s a. p. 17. l. 2 for or r. for; l. 11 dele is attracted. p. 26. l. 20. and 21. r. $p : x :: t^2 : T^2 + O^2 : O^2$, that is $p : x :: t^2 + O^2 : T^2 + O^2$ and therefore $\frac{p}{x} = \frac{T^2 + O^2}{t^2 + O^2}$

p. 40. l. 2. r. Branches. p. 65. l. 18. r. Sudorificks. p. 145. l. 9. for a hundred r. a thousand. p. 176. l. 8. for Secretion r. Section.

O F

Animal Secretion.

IN explaining the manner, how the several Fluids of the Animal Body are separated from the Blood, I shall shew,

First, *How they are formed in the Blood, before they come to the place appointed for Secretion.* And,

Secondly, *I shall demonstrate in what manner they are separated from the Blood by the Glands.*

The Blood of all Animals, when drawn out of the Body, does naturally, and of itself, divide into two different parts: Of which the Red does in a little time coagulate, but

The Blood consists of attracting Particles.

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Of Animal Secretion.

the Serum remains fluid. If we view a drop of Blood with a Microscope, we discern a number of Red Globules swimming in a limpid Fluid; and perceive how the Globules, attracting one another, unite like Spheres of Quicksilver, which, as they touch, run into one another: And consequently the Blood divides into two parts.

*The Serum
consists of
attracting
Particles.*

After the Coagulation of the Red Globules of the Blood, if we examine the Serum with a Microscope, we find in it likewise a great number of Corpuscles of various Figures and Magnitudes, swimming in a limpid Fluid. These do not attract and unite with one another as the former did, till some part of the Fluid, in which they swim, has been evaporated by Heat; and then they likewise attract one another, and form a Coagulum, as the Globules did. This

This therefore is matter of fact, that the Blood consists of a simple and limpid Fluid, in which swim Corpuscles of various Figures and Magnitudes, and endued with different Degrees of an attractive force. Now of such Particles, as the Blood consists of, must the Fluids be composed, which are drawn from it; and as in the Blood the Particles attract one another, and cohere together, so likewise may the Particles of the Fluids, which are separated from it.

Most of the Liquors we know are form'd by the Cohesion of particles of different Figures, Magnitudes, Gravities, and attractive Powers, swimming in an aqueous Fluid, which seems to be the common Basis of all. Why are there so many sorts of Water, differing from one another in Properties? Is it not, because of the Corpuscles of Salts and Minerals

Most Fluids consist of attracting Particles.

with which the Element is impregnated? What else is Wine, but Water impregnated with the Particles of the Grape, and Ale with Particles of Barley? Are not all Spirits the same Fluid saturated with saline or sulphureous Particles? And all Liquors are more or less fluid, according to the greater or smaller Cohesion of the Particles, which swim in this Aqueous Fluid; and there is hardly any Fluid without this cohesion of Particles, as is apparent by the Bubbles which stand upon the Surface of Water, Wine, and even of some Spirits.

The Secretions consist of attracting Particles.

But that some of the Fluids, which are secreted by the Glands from the Blood, are actually composed by the Cohesion of several sorts of Particles, is very evident. We know that in Milk there are three or four several sorts of Substances, and yet when

Of Animal Secretion.

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when it is examined by the Microscope it appears, like Blood, to consist of very small Globules, swimming in a limpid Fluid. Urine has the same Appearance, and contains perhaps more Principles: And there is no doubt but that Tears, Spittle, and Sweat are all compounded Liquors. If some of the Fluids which are secreted by the Glands are not easily resolved into their compounding Parts, we can no more conclude from thence, that they are not compounded, than we can that the Blood is not, because it does not separate into about thirty different Fluids of which it is composed, and which are constantly extracted from it by the Glands.

If the Particles, which attract one another, are still more powerfully attracted by the Particles of the Fluid in which they swim, than by

The Reason why it is not evident in all.

one another, they can never of themselves separate from the Fluid; and this is the case of all Salts dissolv'd in a large quantity of Water and of Urine, when it neither breaks nor settles. But if the Particles, which swim in the Fluid, are more strongly attracted by one another, than they are by the Fluid in which they swim, then this Fluid must necessarily go into parts; and the Corpuscles uniting, will either sink, swim, or ascend in the Fluid, according to their specifick Gravities, unless there should be so many interstices within the coagulated Mass, as will receive the greatest part of the Fluid. From hence it is plain that the red part of the Blood consists of Particles which attract one another, more than they do the watry Fluid, in which they swim; and that the other Particles

ticles, which are in the watry Fluid of the Serum, are more attracted by it than by one another. But if part of this watry Fluid be evaporated, by this means, the Particles attracting approaching nearer, the Force of their Attraction is increased, and then they unite; and consequently this force must be much stronger in Particles that are very nigh one another, than when they are at a distance.

This Power, by which the Particles of the Blood attract one another, is the same with that which is the Cause of the Cohesion of the Parts of Matter: And was first communicated to me by my Brother at *Oxford*, above seven Years ago; who had no sooner discovered it, but he deduced from it the Cohesion of the parts of Matter, the Cause of the Elasticity of Bodies, of Fer-

This Attraction is an universal Power in Matter.

mentations, Dissolutions, Coagulations, and many other of the Operations in Chymistry. And since it will appear, that the whole Animal Oeconomy does likewise depend upon this attractive Power; it seems to be the only Principle, from which there can be a satisfactory Solution given of the *Phænomena*, produc'd by the *Minima Naturæ*; as that other attractive Principle, which is of a different kind from this, and was first discovered by the incomparable *Sir Isaac Newton*, demonstratively explains the Motions of the great Bodies of the Universe: Which is not in the least disturb'd by the attracting Power we now speak of, which only exerts its self in Particles that are at a small distance from one another. Now, that there is such an attractive Power in Nature as this we have mentioned, I think,

can be denied by none, that duly consider the Experiments and Reasons given for it, by Sir *Isaac Newton*, in the Questions annexed to the Latin Edition of his *Opticks*.

From this Principle that the Blood consists of Corpuscles of various Figures and Magnitudes, and endued with various Degrees of an attractive Power, and that of such Particles the Fluids secreted by the Glands are composed; I say, from this Principle (for which we have ocular Demonstration) I shall endeavour to shew how the Corpuscles that compose the Secretions are formed in the Blood, before they arrive at their secreting Glands: having first laid down the following Propositions, being only so many of the Laws of Attraction as at present we have occasion for, the rest
being

being contained in my Brother's Theorems, published in the *Philosophical Transactions*.

*Some Laws
of Attraction
in
small Particles
of Matter.*

Prop. I. *There is a Power in Nature by which each Particle of Matter attracts every other Particle, with a Force that increaseth in a greater Proportion than that, by which the Squares of the distance decrease, viz. in a reciprocal triplicate, or quadruplicate Proportion to the distances.*

For were the Particles, that compose the attracting Body, endued with a Power that attracted only with a Force reciprocal to the Squares of the Distances, the Attraction would not be much stronger at the Contact, than at some determined Distances from it: As is evident in the Case of Gravity, which arises from a Power of attracting reciprocally as the Squares of the Distances;

ces; Bodies being of the same Weight, when they touch the Earth, as they are at an hundred Feet distance. But by all Experiments, this Power is much greater at the Contact, or Extremely near it, than at any determined distance. The Particles of Salt dissolved in a large quantity of Water, do not sensibly attract one another, till part of the Water has been evaporated; by which means approaching each other, their attractive Force increases, they run to one another, and uniting form Crystals, whose Parts have a strong Cohesion. And therefore the Force, by which each Particle attracts every other Particle, must encrease in a much greater Proportion, than that by which the Squares of the distances decrease.

Prop.

Of Animal Secretion.

Prop. II. *The attractive Force is cæteris paribus proportional to the Solidity of the Particles.*

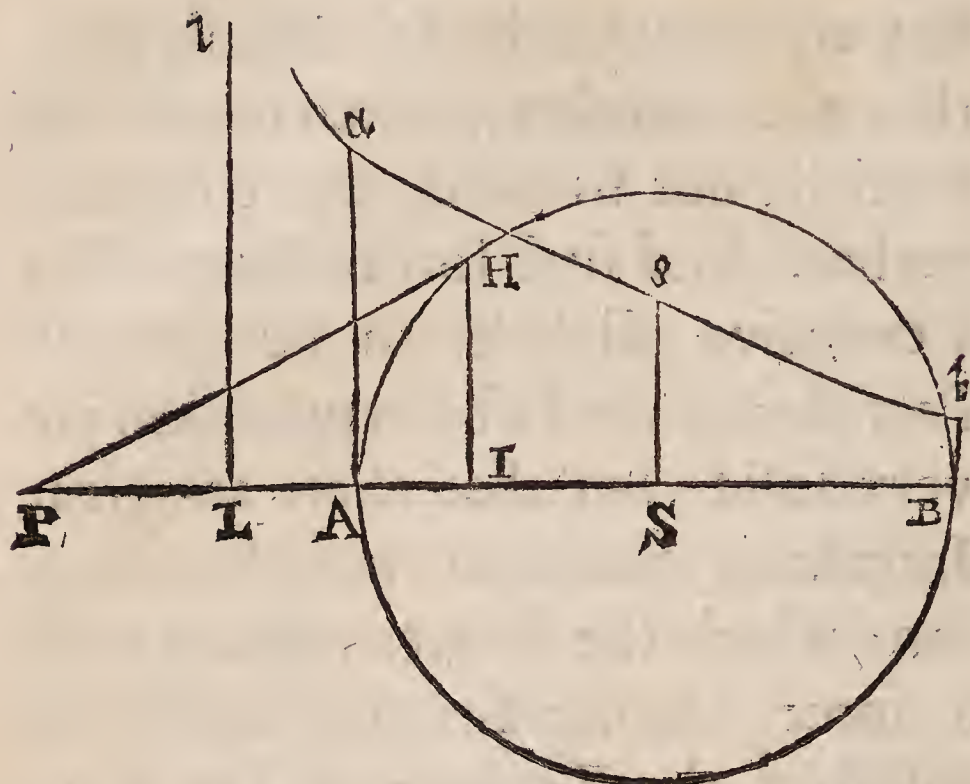
The attractive force of a Particle is composed of the Sum of all the Attractions of the Parts of that Particle: Now these Parts are most numerous in the most solid Particles, and therefore *cæteris paribus*, their attractive Force is strongest.

Schol. This Proposition is to be understood of the smallest Particles of Matter, and not of the Corpuscles made up of those Particles. For Corpuscles may be so compounded, that the most solid and compact Particles may make up the lightest Corpuscle, if the Interstices between the Particles be large, so that few of them may be diffused thro' a great Space: Such a Corpuscle, tho' it consists of Particles that are endued with a strong attractive Power,

Power, may yet be specifically lighter than another, which consists of Particles not so solid, but closer together. And such sort of Corpuscles I conceive all Salts to be, whose Particles of the last Composition are very solid, but that there are great Interstices between those Particles, into which the Water rushing with a force, being strongly attracted, dissolves the Texture of the Corpuscles.

Prop. III. If Particles of Matter attract each other with a Force, that is in a reciprocal triplicate, or a greater Proportion of their distances, the Force by which a Corpuscle is drawn to a Body, made up of such attractive Particles, is infinitely greater at the Contact, or Extremely near it, than at any determined distance from it.

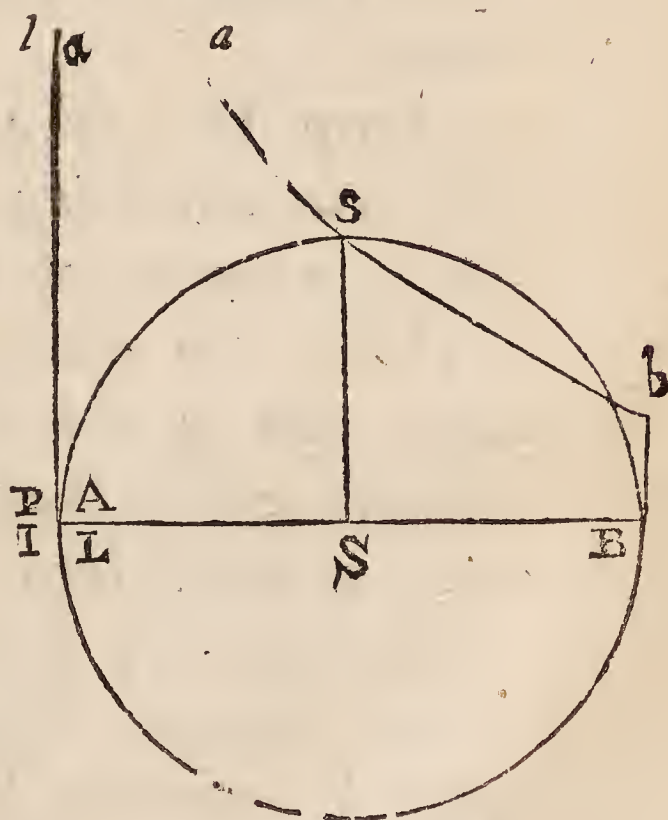
Suppose



Suppose the Sphere A H B composed of Particles, that attract a Corpuscle P with a Force reciprocally proportional to the Cubes of their Distances. Draw the Tangent P H, and from H let fall the perpendicular H I, bisect P I in L, and raise the Perpendiculars L l, A a, S s, B b, and make S s = to S I: with the Asymptots L B, L l thro' s, describe the Hyperbola b B a, and the Area a A B b — the rect-angle

angle $2 AS \times SI$ will represent the Attraction of the Corpuscle P by the 8th Prop. of Sir *Isaac Newton's* Principles.

But when the Corpuscle P comes to the Sphere, and touches in A, then the Points P, L, A, I, and H, coincide, and Aa becomes the Asymptot of the Hyperbola, and the Area aABba becomes infinite, and the rectangle $2AS \times SI$ being finite, the Area aABba — $2AS \times SI$ will be infinite; and consequently the Force, by which the Corpuscle P is attracted by the Sphere, will be likewise Infinite.



If the Sphere consists of Particles that attract in a reciprocal quadruplicate Proportion of their distances, the Force, by which a Corpuscle will be drawn to the Sphere, will be as $\frac{1}{PS^3 \times PI}$. Now when the Corpuscle comes to touch the Sphere, PI becomes $= 0$, and consequently whatever is divided by it, becomes infinite, and therefore the attractive Force of the Sphere at the Contact, being proportional to $\frac{1}{PS^3 \times PI}$, will be infinite.

Prop. IV. *If a Body consists of Particles attracting with a Force that is in a reciprocal Proportion to the Cubes of the distances, or in a greater; and if this Force is not infinitely greater than the Force of Gravity at the Point of Contact, or extremely near it, at any determined distance from the Point of Contact, it must be infinitely less than the Force of Gravity.*

This

This is clear by the last Proposition: Or in that Case, the Force of Attraction in a Corpuscle removed from the Contact is infinitely less than at the Contact, or extremely near it; but at the Contact it is not infinitely greater than the force of Gravity by Supposition: therefore the Force, by which a Particle removed at a determined distance from the attracting Body is attracted, is infinitely less than the Force of Gravity.

Prop. V. The force, by which the Particles of Matter attract each other, when extremely near the Contact, is not infinitely greater than the force of Gravity.

This is evident: because in the strongest Cohesion of Particles touching one another, we find that the Weight of some Bodies will pull the Particles asunder, tho' that Body may be prodigiously greater and
C heavier

heavier than the Particles united. Sir *Isaac Newton* calculates from the Inflection of the Rays of Light, that this force near the Contact is 10000 0000 0000 0000 greater than the Force of Gravity.

Corol. Particles removed at a determined distance from the Body attracting, are not acted upon by it; because this Force must then vanish, or, which is the same thing, be infinitely less than the Force of Gravity.

Prop. VI. *A large Particle attracts not more strongly than a small one of the same Solidity, but a Diversity of Figures causes different Degrees of Attraction in Particles, that are otherwise the same.*

This attractive Power acts only on such Particles as are extremely near; and therefore of a large Particle, the remotest parts conduce nothing

nothing to Attraction: and for the same Reason the attractive Force varies, according as the Particles are Cones, Cylinders, Cubes, or Spheres, and *cæteris paribus* a Spherical Particle, has the strongest attractive Power.

Prop. VII. *If Particles swimming in a Fluid, attract one another more strongly, than they do the Particles of the Fluid, the Force, by which they come to each other, will be that by which their attractive Force exceeds the attracting Force of the Fluid.*

For the Particles of the Fluid, that lie directly between the attracting Particles, being more pressed than the other ambient Particles; they will from the Nature of Fluidity, with that excess of Pressure, drive the other Particles out of their places, and make way for the attracting Particles to come together.

Of Animal Secretion.

Prop. VIII. *If Particles swimming in a Fluid, are more attracted by the Fluid, than by one another, they will recede from one another, with a Force that will be equal to the difference of their mutual Attraction, and the Attraction of the Fluid.*

For the ambient Particles of the Fluid attracting more strongly, will with their excess of Force draw the other Particles to themselves, and make them to recede from one another.

Prop. IX. *The Force, by which Particles attracting one another cohere, is greater cæteris paribus, where the Contact is greater.*

For the parts that are farther remov'd from the Contact, conduce nothing to the Force of the Cohesion; and a greater Power must be requisite to separate two Particles,
which

which cohere in two points, than two Particles which cohere only in one point, if the Degree of Cohesion be equal in each point. Thus two polished Marble-stones (suppose a Foot square) adhere more strongly than any other two Bodies of a Foot square, which are not so solid, but have more Pores and Interstices between their parts, and which will not receive so good a polish, by which the parts come to a close contact with one another.

Prop. X. If the attracting Corpuscles are elastick, they must necessarily produce an intestine Motion, greater or lesser, according to the Degrees of their Elasticity and attractive Forces.

For after meeting they will fly from one another with the same Degree of Velocity (abating the resistance of the Medium) that they met

C 3 together

together with ; but when they approach other Particles in their Refilition , their Velocity must increase, because they are afresh attracted, and therefore meeting a second time, they will recede with a greater Velocity than they did at their first Concurfion : and so their Velocities will be increas'd by every Concurfion and Refilition, which must necessarily produce a sensible intestine Motion ; and the stronger their attractive Force, and the greater their Elasticity , their Concurfions and Refilitions will be the more sensible.

Prop. XI. *Particles attracting one another in a Fluid, moving either with a swift or slow progressive Motion, attract one another just the same, as if the Fluid was at rest, if all the Particles move equally ; but an unequal Velocity of the Particles does mightily disturb their Attractions.*

The

The Particles do all by Hypothesis move equally, and consequently the progressive Motion of the Fluid does not alter their distances, that is to say, it does not repel them from one another; and consequently they must attract one another with the same Facility, as if the Fluid was at rest. But if some Particles move faster than others, some must change their Position in respect to each other, and those parts, which by the force of Attraction would have come together, will by this unequal Motion be carried from one another. Thus Salts do not crystallize, nor the terrestrial Particles of Urine attract one another, and unite, till the Water, in which they are dissolved, is almost cold; and the intestine Motion of its Particles, caused by heat, is quieted.

These are the Laws, by which Secretions are first formed in the Blood, before they are separated by the Glands. The Particles of the Blood returning by the Veins mutually attract one another, and cohering form Globules too big for any Secretion; and therefore there was an absolute necessity, that they should be broken and divided in the Lungs by the force of Respiration: which because it is commonly thought to be inconsiderable, by reason we are not sensible of it, I shall therefore here make an Estimate of it.

*The Force
of the Air
upon the
Blood in
breathing
determined*

It is demonstrated by the Writers of Hydrostaticks, that Weights, which force out of the same Tube equal Quantities of the same Fluid, are to one another as the Squares of the times the Fluid is forced out in. But if the times are equal in which
the

the same Quantity of the Fluid is forced out thro' unequal Tubes, then the Powers are reciprocally as the Orifices of the Tubes; and therefore Powers which thrust out the same Quantity of a Fluid thro' unequal Tubes, are to one another in a reciprocal Proportion, compounded of the Squares of the Times and Orifices of the Tubes.

Now that I might know by what force the Air is thrust out of the Lungs in Expiration, I took a thin Hogs-bladder, which I could easily blow up with the Breath of one Expiration; and having moistened it, that it might neither resist the Air in blowing up, nor the Weights which were laid upon it, I fix'd a small Tube, whose Diameter was $\frac{1}{10}$ part of an Inch, to the Neck of the Bladder; then filling the Bladder with Air, I put a Weight of
2 lib

2 *lib* 4 Ounces on the top of it: And having repeated the Experiment several times, I found that this Weight squeez'd all the Air out of the Bladder thro' the small Tube in the space of 25 Vibrations of a Pendulum, which vibrated Seconds of a Minute.

Let P stand for 2 *lib* 4 Ounces, or 36 Ounces, O for the Diameter of the Tube, T for the time of 25 Seconds, and suppose \propto to be the Power, by which the Air is thrust out of the Lungs in Expiration, o the Diameter of the Aperture of the *Larynx* (which I shall suppose to be $\frac{3}{10}$ parts of an Inch) let t be the Time spent in an ordinary Expiration, which is commonly $1''\frac{1}{4}$ or $1''25$. then $P : \propto : T^2 : t^2 : T^2 + o^2 : O^2$, that is $P : \propto : t^2 \times o^2 : T^2 \times O^2$, and therefore $\propto = \frac{P \times T^2 \times O^2}{t^2 \times o^2}$

$$= \frac{36 \times 625 \times .01}{1.5625 \times .09} = \frac{225}{0.140625} = 1600$$

Ounces

Ounces, equal to 100 *lib*: which is the force by which the Air is thrust out of the Lungs every Expiration. But being Action and Reaction are equal, the Pressure of the Air upon the Lungs every Expiration is equal to the Pressure of an 100 *lib* Weight. If the Gravity of the Air was always the same, and if the Diameter of the Trachea Arteria, and the time of every Expiration were equal in all, this Weight upon the Lungs would be always the same. But since we find by the Barometer, that there is 3 Inches difference between the greatest and the least Gravity of the Air, which is a $\frac{1}{10}$ part of its greatest Gravity; there must be likewise the difference of ten *lib* Weight in its Pressure upon the Lungs at one time and another: for the Momenta of all Bodies, moved with

The effects of the different Gravities of the Air considered upon Asthmatick People.

with the same Velocity, are as their Gravities. This is a difference, which such as are Asthmatick must be very sensible of, especially if we consider that they likewise breath thicker, that is, every Expiration is performed in less time; if in half the time, and the same Quantity of Air drawn in, then the Weight of the Air upon the Lungs must be 400 *lib*, of which $\frac{1}{10}$ part is 40 *lib*, and consequently Asthmatick People upon the Rise or Fall of the Barometer, feel a difference of the Air almost equal to half its Pressure in ordinary breathing. Again, if the *Trachea Arteria* is small, and its Aperture narrow, the pressure of the Air increases in the same Proportion, as if the times of Expiration were shorter: and therefore a shrill Voice is always reckoned amongst the prognostick Signs
of

of a Consumption, because that proceeds from the narrowness of the *Larynx*, or *Trachea Arteria*; and consequently encreases the Pressure of the Air upon the Lungs, which upon every Epiration beats the Vessels so thin, that at last they break, and a Spitting of Blood brings on a Consumption apace.

I suppose, no body doubts whether this Pressure of the Air upon the Lungs in breathing be sufficient to break the Globules of the Blood, and to dissolve all the Cohesions they might contract in their Circulation thro' the Arteries and Veins. And when the Blood is thus dissolved and thrown out by the Heart into the *Aorta*; it is evident that the reunion of the Particles requires more or less time, according to their several attractive Powers, even tho' they all moved with the

By this Pressure of the Air, the Cohesions of the Globules of the Blood are dissolved.

same

same Velocity, and in the same Direction.

*How the
Union of
the Parti-
cles is hin-
dered near
the Heart.*

But neither doth this happen, for a Fluid moves thro' a Cylindrical or Conical Vessel (such as the Arteries are) with a greater Velocity at the *Axis* than at the Sides. And again, the Blood is thrust into the *Aorta* by the whole Force of the Heart, and Fluids when they are pressed press *undequaque*, by which means the Arteries are dilated, and the Blood moves not only forwards, but likewise presses perpendicularly on the Sides of the Arteries; and as the Sides of the Arteries (being Elastick) return, they press the Blood from them every way, which must produce an intestine Motion, and by the 11th Proposition hinder the Attraction of the Particles, and by this frequent and strong Collision of the Particles
of

of the Blood against the Sides of the great Arteries, the Cohesions of the Particles, if any of them happen to unite, will be immediately dissolved. Again, this intestine Motion must greatly increase upon the account that many of the Particles of the Blood are elastick: for by this Resistance of the Sides of the Vessels, they must necessarily hit one against another, and being elastick, reflect from one another, and so increase the intestine Motion of the Blood by the 10th Proposition. Upon this intestine Motion of the Blood depends its Heat, which therefore is every where proportional to the *impetus* of the Particles against the Sides of the Vessels, supposing the Elasticity of the Particles every where the same. Now the *Impetus* of the Particles against the Sides of the Vessels decreases, as
s the

the Sum of the Cavities of the Vessels increases: and consequently where the Sum of the Cavities of the Vessels is greatest, there the intestine Motion of the Blood is least, and the attractive Power of the Particles *cæteris paribus* is greatest.

*The Effects
of Steel.*

By the by, we may observe how that Steel, being an elastick Body, heats the Blood more than any other Mineral; and how by its Elasticity, the Force of its own Particles in removing Obstructions, as well as those of the Blood, increase, and therefore it is a better Deobstruent, than some other Minerals, which have a greater Gravity.

*What Par-
ticles unite
first.*

The Particles, which unite first after the Blood is thrown out of the Heart into the great Artery, must be such as have the strongest attractive Force; and such as have the least, unite last: and all the intermediate

intermediate ones according to their several Natures. The Particles endued with the strongest attractive Powers, are by the 2d and 6th Proposition, the most solid spherical Corpuscles, and the Quantity of their Contact being the least by the 9th Proposition, the Secretion, which they compose, must be the most fluid, and such is the Liquor in the *Pericardium*.

The Salts are Corpuscles that are strongly attracted, and have a most close Union with the Fluid of Water; for tho' the Lungs may divide the Particles of Salt from one another, yet still they firmly adhere to the aqueous Humour in which they swim, and therefore they may likewise at first be drawn off: upon which account the Kidneys have their Situation so near to the Heart. And indeed, they could not have

*The Reason
of the Situation of the
Kidneys.*

D been

been placed at a greater distance, and have separated such a Quantity of Urine as they now do, not only upon the account of the great Quantities of Blood they receive where they are; but likewise, because if they had a more distant Station, other Particles must have united with the Salts and aqueous Particles (as in their present Station some terrestrial Particles do) and consequently the Urine could not have been distilled such as it is now, or at least but in a small quantity.

What Particles are longest in uniting.

The Corpuscles, which are the slowest in uniting, must be such as have the weakest attractive Force, which by the 2d and 6th Proposition, are such as have the least Solidity, and such as have their Surfaces the most extended; and therefore Corpuscles, which have plain Surfaces, are longer in uniting than

than spherical Corpuscles, but when united, they cohere more strongly by the 9th Proposition, and compose the most viscid Fluids: and therefore the most viscid Secretions, such as the Mucilage of the Joints, are separated at the greatest distance from the Heart, where the Sum of the Cavities of the Arteries is greatest, the *Impetus* of the Blood against the Sides of the Vessels (which is always proportional to the Velocity of the Blood) smallest, and consequently where the Particles move almost with an equal Velocity, and therefore the Attractions of the weakest are not disturbed by the 11th Proposition.

The Gall which is secreted by the Liver, and the Seed by the Testicles, do seem to be two considerable Objections against what has been said. But I will make it appear that they

are so far from proving any thing against this Doctrine of Secretions, that they are the greatest Arguments that could possibly be urged for the truth of it. Nothing does more evidently demonstrate the Intentions of Nature in her Operations, than the various Methods she is sometimes forced to take to bring the same thing about.

This Doctrine illustrated by the Separation of the Gall in the Liver.

This is most eminently remarkable in the Secretion of the Gall: which, being to be mixed with the Chyle as it comes out of the Stomach into the *Duodenum*, could no where be so conveniently fecerned from the Blood, as where the Liver is placed. Now had all the Branches of the Celiac Artery carried all the Blood to the Liver, from which the Gall was to be separated, it is evident, considering the nearness of the Liver to the Heart, and the intestine Motion of the

the

the Blood, that so viscid a Secretion, as the Gall is, could never have been formed in the Blood, and consequently, could never have been secreted by any Gland in that place. In this case Nature is forced to alter her constant Method of sending the Blood to all the parts of the Body by the Arteries. Here she forms a Vein (which is no Branch of the *Vena Cava*, as all the others are) and by it she sends the Blood from the Branches of the Mesenterick and Celiac Arteries (after it has passed thro' all the Intestines, Stomach, Spleen, Caul, and Pancreas) to the Liver. By this extraordinary Contrivance the Blood is brought a great way about, before it arrives at the Liver; and its Celerity is extremely diminished, that all the Corpuscles, which are to form the Gall may have sufficient time to attract

one another, and unite before they come to their discerning Vessel. And thus we have found out the use of the *Porta*, which, notwithstanding it makes so considerable a Figure in the animal Body, yet perhaps no part was ever less minded, or had its use less understood by the Writers upon the animal Oeconomy.

But that this is most certainly the use of the *Porta* will more evidently appear, if we consider what Nature still does farther in prosecution of the same Design.

The Cavities of all the Arteries increase as they divide. The Sum of the Branches, which rise immediately from the *Aorta*, is to the *Aorta* as 102740 is to 1000000: but as if this Proportion was too little to effect the design of Nature, before the Blood arrives at the Liver, the Branches, which immediately

diately spring from the Trunk of the Mesenterick Artery, increase in a much greater Proportion. The Figure of this Artery, as it lies in the middle of the Mesentery, is after this manner.



And in that Body, from which I took the following Proportions, I found 21 Branches to spring immediately from its Trunk. In such parts of which the Trunk of the Mesenterick Artery is

	15129
The 1 st Branch is	2136
2	1936
3	2136
4	2104
5	4489
6	1936

D 4

7

7	2601
8	3136
9	1681
10	3025
11	625
12	1369
13	1024
14	1849
15	1936
16	529
17	729
18	1156
19	1024
20	1156
21	841

The Sum of all 37418

By these Proportions it appears, that the Sum of the first Branch is much more than double to the Trunk of the Mesenterick Artery; and therefore the Velocity of the Blood in them is much less, than
 41 half

half what it is in the Trunk. But because the other Branches do not exceed one another so much, I shall therefore suppose that the Branches are only double to their respective Trunks, and that there are only six Series of Divisions between the Trunk, and the evanescent Artery: whereas most of the Branches have so many Series, whilst they run upon the Mesentery, and many more upon the Intestines, so that what we may have exceeded in reckoning the Branches double to their Trunks, is more than made amends for in supposing so few Divisions. Now from this easie Supposition, the Velocity of the Blood in the several Series will decrease in the same Proportion as these Numbers increase 2, 4, 8, 16, 32, 64. And therefore the Velocity of the Blood in the evanescent Artery will be

64 times less than it is in the Trunk of the Mesenterick.

As the Trunk of the Mesenterick Artery bears a lesser Proportion to its Branches, than the *Aorta* does to its Branches; so the Branches of the Mesenterick Artery are likewise less in Proportion to their conjugate Veins, than the *Aorta* is to the *Vena Cava*. The descending Trunk of the *Aorta* below the Emulgents is to the *Vena Cava* at the same place, as 324 is to 441. But a branch of the Mesenterick Artery is to its corresponding Branch of the *Porta*, as 9 to 25: and therefore the Blood in the Branches of the *Porta* moves above 177 times slower than it does in the Trunk of the Mesenterick Artery, and that only upon the account of the encrease of the Diameters of the Vessels. So necessary was it to abate the
the

the rapid intestine Motion of the Blood, which might hinder the coalescence of the Particles for the Formation of the Bile. The Blood is indeed no where without an intestine Motion; but where the Sum of the Cavities of the Blood Vessels is greatest, there the intestine Motion being most languid, the Particles which hit against one another, do not refile, but unite together; and a very languid intestine Motion, by bringing Particles nearer to one another, which otherways would not have come together, conduces to encrease the Combination of Particles.

We have now seen how Nature has provided for the Formation of the Bile in the Blood, which passes thro' the Mesenterick Artery. We shall next consider what Care is taken of that

which

which is conveyed by the Celiac Artery to the Liver: For it seems it was necessary to send a larger quantity of Blood to the Liver, than could be disposed off thro' the Intestines. Part of the Blood of the Celiac Artery is spread upon the Stomach and Caul, and its Velocity diminished, as we have seen in the Intestines; but still all the Blood, which these parts could receive, was not sufficient for the Liver, and there was no more room for the division and expatiating of the Vessels thro' such a large Space as the Mesentery, and a long Tract of Guts. How therefore must the Velocity of the rest of the Blood (to which the Intestine Motion is always proportional) be abated? Nature has here another extraordinary Contrivance, she empties the Blood entirely out of the Vessels into a large
spongy

spongy Bowel, or rather Cistern provided for that intent and purpose. I know not the Dimensions of the Splenick Artery, but the Circumference of the Celiac being $\frac{1}{2}$ an Inch, or ,5, its Square is ,25; and therefore the Square of the Splenick, which is a Branch of it, cannot be above ,18. Now the Dimensions of the Spleen are 6 Inches in length, 3 or 4 in breadth, and 2 in thickness. I shall therefore make this easy Supposition for the more ready Calculation, that it is a Cylinder of 2 Inches Diameter, and therefore the Square of its Circumference being 36, the Blood must move 200 times slower in the Spleen, than in the beginning of the Splenick Artery: and is longer before it gets to the Liver, than that which passes thro' all the Intestines. Is not this the long sought
for

for use of the Spleen? So productive is one simple Truth of many others.

From all this Art and Contrivance it is evident Demonstration, that the Intent of Nature was to diminish the Velocity of the Blood, and that such a slow Motion was absolutely necessary for the fecerning of the Bile in the Liver. If the Humours which are separated by the Glands are at all times and places the same in the Blood, and not formed after the manner demonstrated, what need was there for diminishing so considerably the Velocity of the Blood? let the Blood move fast or slow, they would be always the same, and always in an equal aptitude to be fecerned.

The Proportion of the Bile to the rest of the Blood.

The Particles, which compose the Bile, bear a very small Proportion to the rest of the Blood, as is evident

evident from the great quantity of Blood that is carried to the Liver, and the small quantity of Bile that is separated by it. In a large Dog, whose *Ductus Cholidochus* was near as big as a Man's, I could never gather above two Drachms in an Hour. Now there is thrown into the *Aorta* every Hour about 4000 Ounces of Blood: and it appears by the Proportions of the Arteries, that the Mesenterick and Celiac are to the rest, as 1 to 8; and therefore 500 Ounces of Blood: are carried every Hour to the Liver. And since only two Drachms of Bile are separated from it, the Bile must be to the Blood, at least, as one is to two thousand. It is by reason of this small Proportion of the Bile to the Blood, that it was so necessary to allow so much time for the Attraction of the Particles which form

the Bile. From this Contrivance of the *Porta*, the Bile receives another Advantage, not less considerable than the Diminution of the Velocity of the Blood: and that is the Blood passing thro' so many different parts before it comes to the Liver, parts with the greatest part of its *Lympha*, by which means the Particles, that compose the Bile, approaching nearer to one another, are by their mutual Attraction sooner united. And the consideration of these two Contrivances does highly confirm the truth of this Theory of Secretion: For the Diminution of the Velocity of the Blood, and the Subtraction of the *Lympha* can agree in no other end, than the uniting of the Particles of the Bile.

What has been said concerning the Bile, does so evidently prove this Doctrine of Secretions, that
there

there seems to be no room to doubt of it, even tho' we could not clear the like Difficulty, as to the Formation of the Seed. Yet here again, we meet with another Manifestation of the truth of it, and we find Nature pursuing the same Intentions, tho' in a different manner, the Structure of the parts not allowing either of the former Contrivances.

The Blood is carried to the Testicles by the Spermatick Arteries; *Of the Secretion of the Seed.* which, contrary to the constant Method of Nature in framing the other Arteries, are sinallest, where they spring from the Trunk of the great Artery, and immediately dilate to a considerable bigness: which evidently shews, that there could be no other design in it, but to retard the Velocity of the Blood. We cannot suppose that the only Inten-

E tion

tion was, that a small quantity of Blood might go to the Testicles: because then there had been no occasion for giving the Artery a different Figure from all others; that narrow Orifice would have been sufficient of its self for that purpose, which the wideness of the Artery immediately afterwards does neither hinder nor further. The Orifices of the Spermatick Arteries were so small, that I could not measure them, when I took the Dimensions of the other Arteries; and yet they are hardly gone from the *Aorta* before they dilate as big, if not bigger than one of the Lumbals, which is 434, 2: Now if we suppose their Orifices to be each 17, 3, then the Blood will move 25 times slower, where the Artery dilates, than it does at its Orifice. Again, we constantly find that all the parts of
4 the

the Body are supplied with Blood by small Arteries from the nearest Trunks. If this Method had been observ'd in sending the Blood to the Testicles, they had received their Arteries from the Iliacks; and they had ran but a little way, before they had come to the end of their Journey. But instead of this, two small Arteries are made to arise from the *Aorta*, a little below the Emul-gents, and to march above a Foot before they come to the Testicles. Now if we consider that the Velocity of the Blood in the Spermatick Artery, is 25 times slower than it is at its Orifice, that is, in the *Aorta*; and that the Velocity of the Blood in the Iliacks, can be but a very little less than it is in the *Aorta*, where the Spermaticks arise; the Blood must move 25 times slower to the Testicles, than if it had gone

the ordinary manner from the Iliacks: and because the Space it runs thus slowly, is at least six times longer than if it had gone from the Iliacks; therefore it must be 150 times longer in going to the Testicles, than if it had gone according to the common Course of Nature. So that the intestine Motion of the Blood is not only allayed, but sufficient time is afterwards allowed the Particles, which are to compose the Seed, to attract and coalesce before they arrive at the Testicles.

Some Objections answered.

Perhaps it may be said, that the *Mucus* of the Nose, and the Wax of the Ear are separated, where the Blood is not so languid as their Viscidity seems to require: But I answer, that they are Fluids which fall into open Passages, where the Air having free Admission, carries off part of their aqueous Fluid; and the

the Remainder becomes thick, as the *Serum* of the Blood does, when heated. Besides, we must remember, that tho' the Cohesion of the Particles depends upon their Figures, yet the Force by which they attract one another, is likewise in Proportion to their Solidities. So that Particles of equal Magnitudes, and similar Figures may cohere equally strongly, yet the most solid will soonest unite. Hence it is, that of two Fluids equally viscid, the heaviest may be separated in Glands nearer to the Heart than the other; and that two Fluids of different viscidities may be separated at the same vicinity to the Heart, if the quantity of the Contacts of the Particles be such, as will make amends for their want of Solidity.

Most, if not all the Secretions contain a greater or lesser Proportion

of the aqueous Fluid, which makes them more or less viscid; yet that which contains the greatest quantity, may consist of Particles endued with a very small and slow attractive Force: and consequently such a Fluid cannot be separated by any Gland so near the Heart, as that which has a less Proportion of the aqueous Fluid, and which consists of Particles endued with a stronger attractive Force; and this last Fluid may be much more viscid than the other, whose Particles are more diluted by the watry Fluid. Now how it comes to pass that a greater or lesser Proportion of the aqueous Fluid is separated in any Gland, I shall shew in the second part of this Discourse.

But that the different Viscidities of the Secretions do not depend only on the greater or lesser Proportion
tion

tion of the aqueous Fluid, is evident from the foregoing Propositions; unless any one can suppose that the Blood consists only of one sort of Particles: which Supposition, besides that it contradicts matter of Fact, can never account for the Secretion of so many different Fluids. And that the Diversity of the Attractions in the Particles is the Reason, why various Velocities of the Blood, and distances from the Heart, are required for secreting of different Liquors, is most evident from what has been said concerning the Bile, and the Seed. If only a greater or lesser Proportion of the aqueous Fluid had been requisite for separating of different Sorts of Fluids, that might have been done any where, as shall be shewn afterwards; and Nature had not been put to

so many Shifts and Contrivances,
as we have already seen.

*Some Fluids may be
secerned
any where.*

As some Fluids are only to be separated in certain Velocities of the Blood, and at certain distances from the Heart; so there may be others that may be separated any where, and in any Velocity of the Blood. These are such as consist of Particles always in an equal Aptitude to be secerned, and tho' some of them may contain several sorts of Particles, yet the Nature of these Fluids does not depend upon the Attraction and Cohesion of their Particles. Such a sort of Secretion is the *Lympha*, which is a watry Fluid secerned in all parts of the Body, for making the Chyle more liquid. If it be said, that since the *Lympha* might have been separated any where, and that it serves only to dilute the Chyle, that there ought

to have been a particular Gland
some where for it in the *Abdomen*,
as being the more proper place:

I answer, that a large quantity of *Lympha* was necessary for diluting the Chyle, as appears by the numerous *Lympheducts*, which discharge themselves into the *Receptaculum Chyli*, *Ductus Thoracicus*, and Subclavian Veins. And if such a quantity had been separated by a Gland or Glands in the *Abdomen*, appropriated to that use, they must have had very large and considerable Arteries. The Liver has $\frac{1}{8}$ th part, and the Kidneys near $\frac{1}{8}$ th more of the whole Blood, which passes thro' the *Aorta*; and if the Lymphatick Glands had had $\frac{1}{8}$ th part more (which is the least they could have had) these three parts would have had near one half of the Blood, and the other half must have served
all

all the rest of the Body : which would have been a very unequal Distribution of the Blood. Besides, Nature is always very simple and frugal in her Operations ; she never is at any unnecessary trouble : and I will shew in the second part of this Treatise how the *Lympha* may be drawn off, by Glands appointed to separate other Fluids ; so that for this Operation she makes no Part, is at no expence of Blood : but she must have been at a very great one, if so much *Lympha* had been drawn off by appropriated Glands.

*Of the Se-
cretion of
Animal
Spirits.*

I take the animal Spirits to be another Fluid of this kind. They, undoubtedly, consist of by far the smallest Particles in the Blood, as appears by the minuteness of their secreting Glands ; and therefore they not being formed by the Co-
hesion

hesion of other Particles, might have been separated any where. Yet the Animal Oeconomy receives a great Advantage by the distant Station of the Brain from the Heart; for if it had been placed nearer, and received the Blood, still divided into its smallest Particles, by the force of the Air in the Lungs; such Particles might have entred the Glands, as, afterwards cohering to one another, might have obstructed such extremely narrow Channels. Now the Brain being placed at such a distance, the Particles, that by their attractive Power form Corpuscles, will have sufficient time to coalesce, and their Magnitude will hinder their entring into the Glands. For if it should happen, that these Particles should enter the Glands, and there unite together, they would then obstruct the Passage

sage to the Nerves, and produce Apoplexies, Palsies, Coma's, &c.

The Particles, of which the animal Spirits consist, being of such extreme Fineness, their quantity can bear but a small Proportion to the other Fluids in the Blood; and consequently there was a necessity of a prodigious Number of Glands to separate them from the Blood; and this is the Reason of the great Bulk of the Brain.

*Of the
Number of
different
sorts of
Particles
in the
Blood.*

The Operations of Nature are always the most easie and simple. Now how much more easie is it to have the several Secretions formed after the manner which has been demonstrated, than to suppose as many different sorts of Particles in the Blood, as there are Fluids separated from it? It is not easie to determine, how many different sorts of Particles are in the Blood. Indeed,

deed, Physick seems in nothing so defective, as in the Knowledge of the Nature of the Blood. But if the same Pains had been bestowed upon it in a Mechanical Way, that have been, in vain, spent in search of its Principles by Chymists; we had long e'er now had a more perfect Knowledge of its Nature, than ever we can have by Chymistry: which can only shew how, by Art, its parts may be altered, not what parts it contains.

A few different sorts of Particles variously combined, will produce great Variety of Fluids, some may have only one sort, some two, some three, or more; and perhaps the aqueous Fluid is the common Basis of all the Secretions. If we suppose only five different sorts of Particles in the Blood, and call them a, b, c, d, e, their several Combinations,

nations, without varying the Proportions, in which they are mixt will be these following.

ab: ac: ad: ae:
 bc: bd: be: cd:
 ce: de: abc: adc:
 bdc: bde: bec: dec:
 abcd: abce: acde: abde:
 bcde: abcde.

But whether there are more or fewer in the Blood, I shall not determine.

*Of the
 Operation
 of Medi-
 cines, which
 alter the
 quantity of
 the Secre-
 tions.*

The manner that Medicines operate, which encrease or diminish the quantity of any Secretion, is both easie and obvious from what has been said. There is no need of giving Medicines Commissions for searching and opening the Sluces of particular Glands; nor have they a general Power to attenuate
 and

and dissolve all the Cohesions of the Blood, for then we might still ask why their Operations appear only on one sort of Glands? Why does Jallap carry the dissolved Humours thro' the Glands of the Intestines, rather than any other? Why does Mercury salivate, or Nitre force Urine? All Theories of Secretions have laboured at this point, which naturally discloses its self in this.

The several Humours being formed by the different Cohesions of the Particles of the Blood, the quantity of Humour secreted by any Gland, must be in a Proportion compounded of the Proportion, that the Number of the Particles, cohering in such a manner, as is proper to constitute the Humour which passes thro' the Gland, bears to the Mass of Blood, and of the Proportion

tion of the quantity of Blood that arrives at the Gland. And hence it follows, that where there is a determined quantity of a certain Humour to be separated, the number of the Particles that are proper to compose the fecerned Liquor, must be reciprocally proportional to the quantity of Blood that arriveth at the Gland: and therefore if the quantity of the Secretion is to be increased, the Number of the Particles is to be increased; if the Secretion is to be lessened, the Number of the Particles, that are proper for such a Secretion, is to be lessened in the same Proportion. Medicines therefore which can alter the Cohesions and Combinations of the Particles, can either increase or diminish the quantity of any Secretion. Thus for example, suppose the Humour, which passeth thro' the

the Glands of the Intestines to be composed of three or four several sorts of Particles, that Medicine which will easily cohere to these Particles, and cohering increase their mutual Attractions, so as they unite in greater Numbers at, or before they arrive at the Intestines, than they would have done if the Medicine had not been given, must necessarily increase the quantity of Humour, which passeth thro' the Glands of the Intestines, if the quantity of Blood which arrives at the Glands is not diminished in the same Proportion, as the Number of the Particles is increased. After the same manner do Diureticks, Sudorifick, and Medicines, which promote all other Secretions, operate.

If Medicines, which encrease the quantity of any Secretion, operate *Specifick Purges.* by uniting to, and augmenting the

F attractive

attractive Force of the Particles, which compose the Humours to be fecerned: may not the Particles of some Humours, sooner, more easily, and strongly unite to the Particles of some sort of Medicines, than to another sort? And consequently, may not different Humours require different purgative Medicines to carry them off thro' the Glands of the Intestines? And does not this reestablish the Doctrine of Specifick Purges, confirmed to the Ancients by Experience and Observation, but rejected by the Moderns thro' a false Philosophy?

The Knowledge of Secretion necessary for the understanding the Nature of Diseases

The Animal Body is nothing but a Machine, whose Actions and Motions are all performed by Fluids, fecerned from the Blood, and Secretion is the Spring of all the animal Functions. By its means the Heart beats, the Blood circulates, the

the Limbs are moved, and the Aliments concocted and digested, and in a word, the whole Animal Oeconomy, and Life depend upon it; the Blood its self seeming to have little other use, besides the recruiting and renewing the secerned Liquors. I say therefore, since Life and Health depend upon the Secretions; so likewise must all Diseases, which are said to be universally in the Blood, and many of those which affect particlular parts. If the quantity and quality of all the Secretions are such as are proper and useful for the several Purposes, for which by Nature they are intended, how is it possible but that the whole Animal Oeconomy must be in right Order, and that Body in a good State of Health? Unless we can suppose an Error in the first Contrivance of the Body; a Suppositi-

on no Man in his Senses can make. But if the quantity of any Secretion exceeds its due Bounds, what Disorders it makes is evident from a Diarrhæa, Diabetes, Epiphora, Sweatings, &c. If the quantity of any Secretion falls short of what it ought to be, the Effects are of no less pernicious Consequence, as appears from a Suppression of Urine in the Kidney, from the Jaundice and a Stoppage of Perspiration. And that the quality of the Secretions altered do likewise create great Disorders, is obvious from the Pains of the Colick, of a Diarrhæa, and Dysentery, from the Sharpness of Urine, which sometimes produces Ulcers in the Bladder and Kidneys; and even the Spittle is known to corrode the Mouth. I have chosen to give most Instances of such Secretions, as are
pro-

properly Evacuations, because their Effects are apparent to every body, and cannot possibly be said to be only a Notion. But if the Alteration of those is of such ill Consequences, what Effects must an undue quantity, or the vitiated Quality of these, which are retained in the Body, and employed about the necessary Functions of Life, produce? The Disorders they create, are not so evidently the Effects of their ill State, tho' by a just reasoning, we may sometimes deduce them; and therefore a right Notion of Secretion must be of the greatest use and Importance, for the understanding of most Diseases.

I shall only instance in a Diabetes, ^{*Of a Diabetes.*} and from this Doctrine of Secretion explain the Nature of that Disease hitherto unknown. The Symptoms, which precede a Diabetes,

are little wandring Pains, and frequent Twitchings of the Tendons. These are followed by a profuse Evacuation of a clammy, sweetish Urine, as if Honey were dissolved in it; which is constantly attended with a Thirst, quick Pulse, Faintness, and loss of Strength: all which depend upon the Flux of Urine, and increase and diminish in the same Proportion with it. The evident Cause of this Distemper is an habitual drinking of strong Liquors, and the more spirituous they are, the sooner and more violently they bring it. But a Diabetes is not always caused by an habitual drinking of strong Liquors, for sometimes it proceeds from some internal and latent Cause. However, the Nature of the Disease is always best known, by considering what

what effects the evident Causes of it produce in the Body.

By an habitual drinking of strong Liquours, it comes to pass in process of time, that the *Serum*, or thin part of the Blood, contains a large Proportion of a spirituous Fluid; or that part of the Serum, which should be Water, is for the greatest part Spirit. Now the Salts of the Urine or Blood, will not dissolve in vinous a Spirit, that is, the Particles, of which the Salts consist, are more strongly attracted by one another, than they are by such a Fluid, as by Experiments it appears. And therefore the Quantity of Salts in the Blood, will be daily increased, and circulating thro' the Capillary Vessels, must irritate the fine Fibres, and cause little Pains and Twitchings all over the Body. But when the Serum is full of these

Salts, the distance between them and the Globules of the Blood will be less; and consequently they will attract the Globules of the Blood, more strongly than the Globules attract one another; and the Globules, or red Part of the Blood, will be dissolved and diffused thro' the Serum of the Blood. And this again is confirmed by Experiments; for nothing does render the red part of the Blood so Fluid, and keep it more from coagulating, when drawn in a Cup, than Urinous Salts and Spirits. When the Red part of the Blood is thus dissolved and united to its Serum, it will with the Serum be carried off thro' the Glands of the Kidneys, and being united to the Salts, will alter their Figures and Properties, as Litharge and Corall do the Salts of Vinegar, giving them a sweet Taste.

All quick Evacuations of the Vessels must diminish the quantity of Fluid, separated in the Glands, as will be seen in the following Treatise about the Quantity of Blood; and therefore the greater quantity of Urine is voided in a small time, the less *Saliva* and animal Spirits will be secreted by their respective Glands: and consequently Thirst, Faintness, and loss of Strength will increase, as the quantity of Urine excreted increaseth.

This being the State of the Blood, it is evident that the Indications of Cure, are to dissolve the Cohesions of the Salts with the Blood, and to carry them off by Urine. These can be answered by nothing sooner or better than Waters, which are therefore to be drunk in large quantities. And of all Waters, those which have a Tincture of
Lime

Lime are best, because Lime does strongly attract Urinous Salts.

Of Rheumatisms.

I could shew the usefulness of this Doctrine, in explaining some Symptoms of Feavers, Rheumatisms, Small-Pox, and some other Diseases, which are not thought to depend upon Secretion; and from thence deduce what things are hurtful, and what useful in the several Methods of curing them: but that would carry me beyond my present Design, and perhaps may more fully be illustrated some time hereafter. I will only take notice, that from this Theory, we have a plain and easie Account of the Thickness of the Blood in Rheumatisms; for it is known, that this Disease arising generally from a Cold, the Orifices of all the cuticular Glands are extremely contracted, so that scarce any Fluid, but the aqueous
can

can pass them: and therefore the other Particles, by the Diminution of the aqueous Fluid being brought nearer to one another, will attract and cohere more strongly. And this Cohesion will be greatest in the Extremities, where the Motion of all the Particles is near equal by the 11th Proposition. And does not this evince the Necessity of diluting the Blood in the Cure of Rheumatisms? This equal Celerity of the Particles of the Blood in the Extremities, is likewise the Reason why the Concretions of the Gout are formed there; unless by frequent Debauches, or a decay of Nature, the Motion of the Blood becomes so languid, that these Particles easily attract one another in the Blood Vessels of the Bowels, where I have shewn that the Motion of the Blood is also very slow:

*Of the
Gout.*

*Of the
Stone.*

and then such Remedies as warm and increase the intestine Motion of the Blood, and thereby disturb the Attraction of the gouty Particles, relieve the Bowels, and send the peccant matter to the Extremities again. To this Attraction of the Particles in the Urine, is owing the Formation of Gravel and Stone in the Kidneys and Bladder, and the Nucleus of the Stone in the Bladder, being almost equally surrounded every where with the Fluid of Urine, its Attractions are almost every where equal; and therefore the Stone is made up of so many parallel Shells or Laminæ. Now from this it demonstratively follows, that copious and liberal drinking must necessarily prevent the growth of both: For by that the attractive Particles are removed at a distance too great to attract

attract one another. Provided always that the Drink be such, as is not highly saturated with Particles, which easily and strongly attract one another; what these Drinks are, they, who know the Nature of the Liquors which are commonly drunk, will easily understand.

As this Principle of Attraction will account for most Diseases; so I doubt not, but that by it likewise the Operations of all sorts of Medicines may be explained. For example, Medicines which thicken the Blood, are such as consist of very small Particles, and endowed with a strong attractive Force, by which easily cohering to the Globules of the Blood, they increase their Attraction to one another, and so produce a Coagulation, or at least a thickening of the Blood. On the contrary, if a Medicine consists of

The Operations of Medicines explicable by Attraction.

such

*The Ope-
ration of
Mercury.*

such Corpufcles, as will eafily unite with the aqueous Particles, and increafe their Attraction; fo that they attract the Globules of the Blood with a greater Force, than thefe Globules attract one another, then will the Globules recede from one another, be diffufed thro' the Serum, and the Coagulum be diffolved. A Gonorrhea is undoubtedly produced by a very active Salt, which being ftrongly attracted by the Humour in the Glands, and uniting to it, like the Acids of Salt and Vitriol to Mercury in the Preparation of Sublimate, forms a very *virulent pus*, which corrodes the Veffels, and produces Ulcers. And as Sublimate lofes its corrofive Faculty, by the Addition of more Mercury, which ftrongly attracts its acid Salts; fo Mercury mixt with the Blood, attracts the acid

acid Salts of the Pox, and uniting to them, carrys them off, either by Stool, Spittle, or otherwise. This Power, by which Mercury attracts acid and sharp Salts, is the Reason why Cinnabar is so good a Medicine in fixt and vagrant Pains, as in a Rheumatism: for the Urine of Rheumatick Persons is found upon Examination, not to contain its due quantity of Salts, which therefore being retained in the Blood turn acid, and produce Pains.

Now, who can doubt of the Truth of a Principle so simple, and yet which like a Master-key opens Works of very different Contrivances, and discloses an Uniformity in all the Operations of Nature; so that every one may see and read the same Thought and Hand in the Contrivance, and framing of every part of the Universe. By it we see
the

the Reason why the Branches of all the Arteries in the Body, have the Sum of all their transverse Sections greater than the transverse Section of the *Aorta*; for if it had been otherwise, there could have been no Mucilage separated for the easy Motion of the Joints, without such a Structure as the Spleen at every Joint, where this Mucilage was necessary. By it the Reason not only of the general Structure of the Vessels is demonstrated, but likewise the Necessity of the Frame and Situation of the particular parts, as of the Lungs, Spleen, *Porta*, and of all the Glands. By it the Nature of the Blood and all the Secretions may be explained. By it the whole animal Oeconomy, and all its Disorders, the several Diseases incident to the Body, the Nature of their Remedies, and the ways

ways of their Operations may be accounted for. This is that grand Principle, by which all the Particles of matter in this Planet are actuated. By which, but with a different force, all the Planets are carried round the Sun; and as the projectile Velocity of the Planets, adjusted to the Sun's Attraction, causes them to move in their several Orbits; so the Velocity of the Blood, adapted to the Attraction of its Particles, causes the several Humors to be secreted at certain distances from the Heart by their respective Glands.

I shall now proceed to the second thing I proposed to shew; which is, *The manner whereby the several Fluids, after they are formed in the Blood, are separated from it by the Glands.*

G

This

This does depend intirely upon the Figure and Structure of the Glands ; which must be therefore first determined. As Truth when plain and evident does of itself dispel all false Opinions, so the true Structure of the Glands being once demonstrated ; there will be no Occasion to refute the Doctrine of Ferments ; nor the Hypothesis of Tubes differing as to the Figures of their Orifices, both which have been several times demonstrated to be false.

That the Glands are nothing but Convolutions of small Arteries, the greatest and most accurat Anatomists of this Age, *Malpighius*, *Bellini*, and *Nuck* have discovered. And indeed that all the Vessels of the Body, in which the Liquors are continually moving, can have

no

no other than a cylindrical or Conical Form, is demonstrable from the Nature of Fluids, whose Pressure is always perpendicular to the Sides of the containing Vessel, and equal at equal Heights of the Fluid: If therefore the sides of the Vessels are soft, and equally yeilding every where (such as are all the Tubes in the Body of a *Fœtus*) they must by the Pressure of their contained Fluid, be equally every where distended; and consequently the Section of such a Vessel perpendicular to its Axis must be a Circle, and therefore the Vessel must be either a concave Cone or Cylinder, or at least such a Figure whose transverse Section is a Circle.

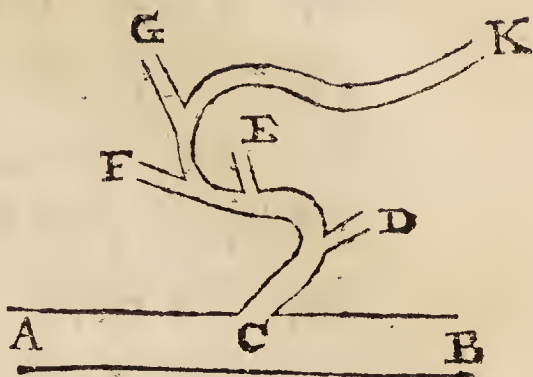
The Circular Orifices therefore of the Glands can only differ in Magnitude, and all sorts of Parti-

cles of a lesser Diameter than that of the Orifice of the Gland may enter it; so that without some farther Contrivance, that Fluid which contains the biggest Particles, must likewise consist of all the Particles of all the other Secretions; neither could any Fluid thicker than the Blood be separated from it, because of the great Proportion of the aqueous Fluid, whose Particles being vastly smaller than any other; and invisible to the best Microscopes, must enter all the Glands, and be mixt with the secerned Fluid.

How this inconveniency may be prevented, and how the Particles of any size may either be separated by themselves, or with any assigned Proportion of the aqueous Fluid, or of other lesser Particles, I shall now endeavor to show.

suppose

Suppose A B to be a small evanescent Artery, and that the Particles of the least size were to be separated from the rest.



From the side of the Artery must arise the Gland or Tube C K, whose Orifice at C is such as is capable of admitting only Particles of the least size, together with the *Aqueous* fluid, these therefore will be separated from all the other Particles of the Blood, and the Tube C K being a Cylinder, they will pass to its further end K, which is supposed to be the Excretory Duct of the Gland.

If the Quantity of the *Aqueous* fluid, separated with the least Particles must be diminished, that such a fluid as is requisite, may pass thro' the Excretory Duct K, from

the Tube C K, you must imagine that several other smaller Canals go out, as at D, E, F, G, whose Orifices are so small, that they admit no other Particles besides those of the *Aqueous* fluid to pass thro' them ; and therefore as the least Particles, together with the *Aqueous* fluid pass along the Tube C K, the *Aqueous* fluid must constantly be diminished, the Quantity of the least Particles still remaining, the same can pass no where, but thro' the Excretory Duct K ; and this Diminution of the *Aqueous* fluid will be always according to the Number of the Canals D, E, F, G, that is in Proportion to the Length of the Tube C K, and therefore according as the Gland is longer or shorter, so the more or less *Aqueous* fluid will pass thro' the Orifice of the Excretory Duct K, and consequently

frequently the secreted Fluid upon this Account be thicker or thinner.

If the Particles of a middle size, between the biggest and the least, are to be drawn off from the rest of the Blood. Let the Orifice at the Gland C be just so big as to admit these Particles, and not any of those that are bigger : These Particles therefore , together with the *Aqueous* fluid, and all lesser Particles will pass thro' the Orifice C, but if the Canals D, E, F, G, are big enough to receive all the other Particles, and too narrow to admit the Particles that are to be separated ; it is evident, that those Particles must arrive at the Excretory Duct K, with what Proportion of lesser Particles is required.

Thus we see how any sort of Particles may be drawn off, either by themselves , or mixt with any

others in any Proportion, and this is done in the most simple manner, only by Arteries, for C K is only a smaller Artery, straight, spiral, or otherwise contorted, and D, E, F, G, are again Arteries smaller than it, and if any of these are so small, as to admit only Particles of *Serum*, they constitute lymphatick *Vessels*; from thence it is that we find *Lympheducts* to arise in great Numbers from those Glands that separate thick Humours, as from the Testicles, Liver, &c.

Of the Quantity of Blood in the Humane Body.

How the
Quantity
of Blood
has been
determin-
ed.

I Know not upon what grounds *Physicians* and *Anatomists* have generally determined the Quantity of Blood in the Humane Body, to be

be between fifteen and twenty five pound Weight. All that I can find is the large Quantities of Blood voided by Persons dying of violent *Hæmorrhagies*; so that according to their several Observations, some have ascribed a greater, and some a smaller Quantity of Blood to the Body. Dr. *Moulin* has allotted by How Dr. Moulin did determine it. much a smaller Quantity than any, and gives us the Method by which he determin'd it in the *Philosophical Transactions*. He says, That in a Sheep, which alive, weigh'd 118 *lib.* he found by bleeding it to death, that it contain'd $5\frac{1}{4}$ *lib.* of Blood, which is less than $\frac{1}{22}$ part of the Weight of the Sheep. That in a Lamb weighing $30\frac{1}{2}$ *lib.* when living, there was but $1\frac{1}{2}$ *lib.* of Blood, which is about $\frac{1}{20}$ part : Now upon the Supposition, that a Man's Blood bears the same Proportion

portion to his Weight, as that of the Lamb's (which is the greatest) had to its Weight, it will follow, that the Quantity of circulating Blood in a Man, weighing 160 *lib.* will not exceed 8 *lib.*

*Neither of
these Ways
just.*

These Estimations (tho' widely different from one another) are both made from the Quantity of Blood voided at an open *Vessel*, and they are both founded upon this Supposition, that almost all the blood in the Body runs out at the Wound; a Supposition I can by no means allow to be true, and which I shall evidently shew to be false. For suppose the right external *Iliack* Artery cut asunder, so as that the Blood may freely flow out of the Wound: How can the Blood which is in the right Leg below the Wound, be emptied? It is cut off from the rest of the Blood above,
which

which should drive it forwards, and all the Assistance it can have from collateral *Branches*, which communicate with it can be but very little, because they themselves can receive but a very small quantity of *Blood*, the *Blood* running all to the Wound, where it finds the least Resistance. The Arteries in the *Leg* can beat no longer, because the Pulse depends upon the Quantity of *Blood* thrown into them every Systole of the Heart, which in this Case is nothing, and these being the only regular Causes of the Motion of the *Blood*, the *Blood* must stagnate in the *Crural Vessels*. All that can be said is, that the great Arteries will once contract, and may perhaps have some small *Vibrations* afterwards, by which they will thrust the *Blood* into the capillary *Vessels*, and their convul-

five

Of Animal Secretion.

five Motions will squeeze the *Blood* forwards in the *Veins* ; but when an Animal once falls into Convulsions by bleeding, it can bleed but little afterwards, the Motion of the Heart ceasing ; besides we know, that neither all Animals, nor all Parts of an Animal are convuls'd upon bleeding to death : And tho' the great Arteries may contract, yet this Contraction must be very languid in the small Arteries, which being innumerable, the greatest part of the *Blood* will be lodg'd in them, there being nothing to drive it out of their contorted Channels, but it must still remain in them, as likewise in the Fibres of the Muscles, which appear of a red Colour, only upon the Account of the *Blood* contain'd within them, their Substance being naturally White. Again, tho' the right and left *Iliack* Arteries do

do in the natural State receive an equal quantity of *Blood*; yet when a Wound is made in the Right, thro' which the *Blood* has an easie Passage, this must receive much the greatest part of the *Blood* which comes down the *Aorta*, and consequently the Circulation of the *Blood* must be very slow in the left *Leg*, and no more *Blood* can come from it, than what is thrust out meerly by the Motion of the *Body*, or what flows naturally of its self in the strait and large *Vessels*, as Fluids will do to come to an *Æquilibrium*; for the same Reason the ascending *Trunk* or *Branches* of the *Aorta* can receive but a small quantity of *Blood*, and therefore the Pulse in the Arteries of the *Brain* must be very languid or none at all, upon which Account the Motion of the Spirits must cease, and consequently

ly

ly that of the Heart. When the *Aorta* begins to be empty (which must quickly happen when the *Blood* runs out at a Wound of a large Artery) then the *Blood* having little or no Resistance, will flow easily into the empty *Vessel*, and a very small Quantity of it will enter the Orifices of the Coronary Arteries of the Heart, the *Valves* covering them, and consequently the Motion of the Heart must cease for want of *Blood*.

The greatest Effusion of Blood not from the largest Vessel.

It is for these two last Reasons, that the larger the *Vessels* are that are wounded, the sooner the Animal dies; and if the *Aorta* it self was cut asunder, there would be a smaller Effusion of *Blood* from it, than from a smaller Artery: For since it is the *Blood* in the *Aorta* that thrusts forward the *Blood* in the *Veins*, and makes it pass from
the

the *Vena Cava* into the right Auricle of the Heart; it is plain, that when the *Blood* in the *Aorta* is intercepted, the *Blood* will be no longer driven thro' the *Veins*, but will stagnate in them, no more of it coming to the Heart, than what by reason of the Fulness of the *Veins* flows into it, and consequently the Heart throwing but a small Quantity of it into the *Aorta*, the Circulation will be quickly stopt, both in the Ascending and Descending Trunks, and there will be no greater effusion of *Blood* than what can be contain'd in the great Artery which holds but little. Wherefoever the Wound is made, so long will the Animal live, as the great Artery keeps full, but whenever that begins to empty, the *Blood* in all its Branches must stop, and consequently the Animal must die.

The

The great-
est Flux of
Blood from
the small-
est Vessels.

The *Vessels* of the *Animal Body* are not meer unactive Tubes, but as they may be gradually dilated, so they can gradually contract again; and as they cannot suffer any violent and sudden Stretching without breaking, so neither can they immediately contract upon any sudden Evacuation. And therefore when any great *Artery* is wounded, the *Animal* dies after a few Pulsations of the Heart, the great *Artery* being immediately emptied: But when a small *Artery* at a great distance from the Heart continues bleeding slowly, all the *Vessels* throughout the whole *Body* gradually contract, so that after many Pounds are evacuated, they may be as full as they were at first, and consequently the *Animal* not so much as faint, the *Vessels* in the *Brain* being still kept full, and the
Spirits

Spirits driven forwards in the *Nerves*; nor can the Animal die till such time as the *Vessels* contract no more. It is for this Reason that we have no Observations, which give account of such large effusions of Blood, at Wounds of the great Arteries, as we have from the small *Vessels* of the Nose, and from the *Hæmorrhoides*; and therefore Doctor Moulin's Determination of the Quantity, of the whole Mass of Blood, which is calculated from the Quantity, voided at the Carotide and Jugular *Vessels*, is much less than what others from the Observation of *Hæmorrhagies* of small *Vessels* have determin'd it to be.

This Contractive or Elastick Power of the *Vessels* is not equal in all Bodies; for in some it is greatly diminish'd by the Viscidity of the Blood, and the Obstruction in the

The Reason of fainting upon any sudden Evacuation.

H Fibres

Fibres and Capillary *Vessels*, and therefore some Men may die of a much less effusion of Blood than others, who perhaps may have a less Quantity of Blood. It is for the same Reason that some Persons faint upon opening a *Vein* of the Arm, whilst others do not. If this Elastick Power of the *Vessels* is strong and great, then as the Blood is let out, the Arteries of the *Pia Mater* contract, and are kept full as well as the Coronary *Vessels* of the Heart, and consequently there is neither Blood nor Spirits wanting for performing the Motion of the Heart; but it happens just otherwise, where this Elastick Tone of the *Vessels* is wanting, that is, to such as have a soft and loose Flesh, a lax and cachectick habit of Body; and therefore when they require bleeding, it is convenient to
stop

stop the Blood at small intervals, to give the *Vessels* time to contract, before the full Quantity that is design'd be drawn off; and if they are ready to faint, the surprizing them, by throwing cold Water in the Face, to cause a sudden Contraction, and the putting of them into an horizontal Posture, that the *Vessels* of the Brain may fill, and the Blood from all the depending Parts, have a more easie Reflux, does prevent it. It is the want of the same Energy of the *Vessels* that causes some to faint upon any sudden Evacuation by Urine, Stool, or any other ways.

That this is the true Reason of fainting upon any sudden or violent Evacuation, and not the drawing off of the Spirits (as is generally said) appears not only from this, that such as faint upon bleeding at the

A Proof
of this Reason.

H 2

Arm,

Arm, do not faint upon Cupping, tho' the same, or a greater Quantity of Blood be drawn off this way, but likewise from the fainting of Persons tapped for an *Ascites*, if it happens, that too great a Quantity of the Waters is drawn off at once. None can suppose that the Spirits, which are in the extravasated *Lympha*, have an immediate Influence upon the Nerves and Heart, that their Subtraction should presently drain the Nerves of Spirits, nor can any think, that the Spirits are so quickly spent, as immediately to suffer upon the account of the want of a Supply from an extravasated Fluid: but the Case is this; In an *Ascites*, the descending Trunk of the *Aorta*, and all its Branches being considerably compressed, the Blood must necessarily dilate the ascending Branches beyond their
natural

natural Bigness; but, when the Waters are let out to any considerable Quantity at a time, the Blood has a more free Passage into the descending Trunk, the Sum of the Cavities of both Arteries is augmented, and the Quantity of Blood thrown out every Systole not being greater, the Arteries cannot be so much dilated, and consequently the Pulse becomes small and weak, and the Spirits therefore are but slowly propelled thro' the Nerves, the Blood flows but in a small quantity into the Coronary *Vessels* of the Heart, and consequently a Syncope must ensue, till the *Vessels* can recover their Tone, and the Blood in all the Arteries comes to an *Æquilibrium*, and therefore it is necessary to rarifie the Blood, and rouse the languid Motion of the Spirits by a Cordial.

That the Compression of the descending Artery must throw a greater Quantity into the ascending Branches is demonstration, and that this Quantity is considerable, and does affect the whole Machine, is evident from the Flushing and Head-ach which some feel after a plentiful Meal, when the Stomach and Guts being loaded, press upon the descending Trunk, and contract its Cavity, which are the Causes why a greater quantity of *Blood* passes into the ascending Trunks; on the contrary, if the Cavity of the descending Trunk should be dilated, there will be a less Quantity of *Blood* thrown into the ascending Trunks, and consequently the Effects on the Animal Body must be at least as sensible.

This contractive Power of the *Vessels* ought to be duly consider'd, before

before the least Quantity of Blood be drawn in most acute, as well as chronick Diseases; for I could easily shew how it may be lost to a great Degree, in a few Hours. And in no Case whatsoever is the drawing off a large quantity of Blood at a time justifiable, since it may be done more safely, and to as good Purpose at small Intervals. It is evident from the Theory of *Secretions*, that both the Quantity and the Quality of the *Secretions* may be altered by *Blood-letting*, and therefore when the *Blood* is upon a Ferment, and generates new Cohesions, of whose Nature we are ignorant, it is a *Risque*, which without evident and cogent Reasons, ought not to be run. But to return,

The great Risque in Bleeding, and the uncertainty of its Consequences.

If we give any Credit to the Observations of Physicians, we must

A greater
quantity of
Blood pro-
ved from
the Obser-
vations of
Physici-
ans.

believe the Quantity of *Blood* in the Humane Body to be above 25 pound Weight. (a) *Rulandus* tells us, that he cured one of a bleeding at the Nose, after he had bled in one Day about Ten pound Weight. (b) *Petrus Borellus* observes, that a full bodied Jovial Taylor lost Ten pounds of *Blood* by the *Hæmorrhoides*, and that he cured him with the Syrrup of dried Roses. (c) *Sckenckius* quotes *Montanus* for one that voided Two pounds and more of *Blood*, by the Piles, every Day for forty five Days together, and was afterwards cured. (d) *Bartholin* says, that he saw one vomit sixteen pound of *Blood* without the least ill Consequence. And he takes Notice of

(a) *Rulandus Curat.* 57. Cent. x.

(b) Cent. iv. Obs. Lviii.

(c) Lib. tert. Obs.

clx.

(d) Cap. de Corde.

one who bled forty eight pound in three Days by the Nose, from *And. Argolus*. (a) *Sckenckius* has several Observations of profuse *Hæmorrhagies* of the Nose. He mentions a Nun of a thin Habit of Body, who by bleeding at the Nose, spitting of *Blood*, and with Urine, voided eighteen pound of *Blood*; she was cured by one Drachm of *Philonium Persicum*. *Brasavolus* cured a Lady of a bleeding at the Nose; the *Blood* which he weighed, besides what fell upon the Ground, Linen and Cloaths, was eighteen Pound. *Marcellus Donatus* recovered one of a bleeding at the Nose, who in two Nights and one Day, bled above twenty pound Weight, as he found by weighing it. And at last he tells us of one

(a) Lib. de capite Obs. cccxxxiii.

who

who in six Days bled forty pound at the Nose.

Now if the Quantity of *Blood* in the Humane Body was not considerably greater than its common Estimate, these Persons could never have surviv'd such profuse effusions of their *Blood*. All of them bled more than Dr. *Moulin* reckons to be in the Body, and many of them more, and almost double of the largest Quantity which is allow'd of by any: So that either we must deny these Matters of Fact, or we must own, that our highest Estimates of the *Blood* fall much short of the true Quantity. Without doubt Men differ in the Quantities of their *Blood*, as well as in the Weight of their Bodies: But none of these above-mention'd are noted to have been of a full habit of Body except *Borellus's* Taylor; and

and it is particularly said of the Nun in *Sckenckius*, that she was a spare and thin Woman, and that her bleeding could not proceed from a *Plethora*.

Having therefore sufficiently proved, that the quantity of Blood in the Humane Body must be much greater than the common Estimation : I shall in the next Place endeavour to shew how much at least it is.

By Blood I understand not only the Fluid in the Veins and Arteries, but likewise that in the *Lympheducts*, *Nerves*, or any other *Vessel* of the Body, because they are all Parts of the Blood, separated from it by the Force of the Heart, and many of them by the same Force return to it again ; and therefore, when I speak of the quantity of blood in the Body, I would be understood

What is here meant by Blood.

derstood to mean the quantity of circulating Fluids, of what kind soever they be, at other Times I shall use the Word in its common Signification.

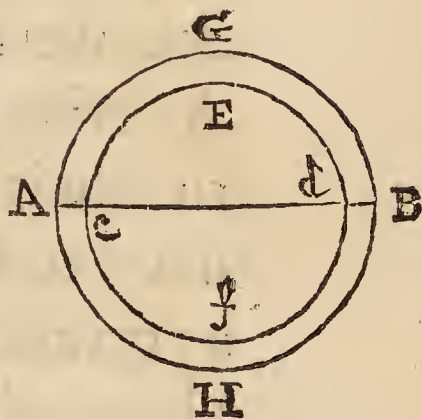
*The whole
Body made
of Vessels
and Fluids.*

I suppose the whole Body is nothing but *Tubes* or *Vessels* full of *Blood* or *Liquors* separated from it. This is now agreed on by all who understand the Fabrick of the Body, and is evident from nice Mercurial Injections of the *Vessels*, and may be plainly seen by *Microscopes*. *Leenwenhoeck* says, That there seemed to be above 10000 Blood-vessels in the space of $\frac{1}{4}$ of an Inch square. You cannot prick your Finger with the finest Needle but it wounds a Blood-vessel. The Fibres of the Muscles (which make by far the greatest part of the Body) are full of Blood, and the Fibres of the Bones

Bones are not without their Fluid,
as I shall shew afterwards.

I therefore consider the *Vessels* The Pro-
portion of
the Fluids
to the Vef-
sels. full of Fluids, as so many solid *Cy-
linders*, and the Coats of the *Ves-
sels*, as so many concave *Cylinders*
of the same height, whose Propor-
tion to one another may be thus

determined. Let *A B*
G H represent the circu-
lar Section of a Vessel, of
which call the Diame-
ter *A B*, *a*, the Diame-
ter *c d* of the Cavity,
a—b. Circles being to one



another as the Squares of their Di-
ameters, the Square of the whole
Section is a^2 , the Square of the Ca-
vity is $a^2 - 2 a b + b^2$, which being
subtracted from the Square of the
whole, there remains $2 a b - b^2$ pro-
portional to the annular Space
A B G H c d f E, and consequent-
ly

ly in a Body compos'd of such *Vessels* filled with Fluids, the Fluids will be to the Solids, or Coats of the Vessels as $a^2 - 2ab + b^2$ is to $2ab - b^2$.

Several
sorts of
Vessels.

Now if the whole Body was composed of Veins or Arteries, it were easie to determine the Quantity of Blood in the Animal Body. But we find, that the Coats of the Arteries have a greater Proportion to their Cavities, than the *Veins* have to theirs, and these again have a greater Proportion to their Cavities, than the *Lymphatick Vessels* have to theirs, and there may be one Proportion of the Nerves, another of the Fibres of the Muscles, and another of the Fibres of the Bones, all which ought to be known before the quantity of blood in the animal Body, can be exactly determin'd.

The

The thickness of the Coats of the Blood-vessels may be thus exactly found: Slit a piece of a Blood-vessel, and reduce it to the Form of a *Parallelogram*, then weigh it in Water, and by that means find the Weight of Water equal to it in bulk. This weight reduced to decimal Parts of an Inch call, d , and suppose the length of the *Parallelogram* equal to e , and its breadth $= c$, its thickness f . Then $d = e c f$ and consequently $\frac{d}{e c} = f$ the thickness of the Coat of the *Vessel*.

Thus a piece of the *Aorta* of a Calf I found to be equal to 0.071897 parts of an Inch of Water, its length was 1.1, its breadth 1.28, and therefore its Thickness was 0.051. The Diameter of the Cavity of this Artery was 0.407. and consequently $a^2 - 2 a b + b^2$ equal to 0.165649, and $2 a b - b^2$ equal to 0.093432,

The Proportion of the Blood in the Arteries to the Coats of the Arteries.

0.093432, and therefore if the whole Body was composed of Arteries or Vessels which had the same Proportion to their Cavities, as the Arteries have to theirs, the Blood would be to the solid part of the Body, as 1.7 to 1, and a body weighing 160 Pound, would have 100 Pound of blood.

The Proportion of the Blood in the Veins to the Coat of the Veins.

After the same manner I found that the thickness of the Coats of the *Vena Cava* of the same Calf was 0.0097. The Diameter of this Vein was 617, its Square is 0.380689, and $2ab - b^2 = 0.02431596$. If therefore the body was composed of Vessels, whose Coats had all the same Proportion to their Cavities, that the Coats of the Veins have to theirs, the Blood would be to the solid part of the body, as 15,6 to 1, and in a body weighing one hundred and sixty Pound, there

there would be above one hundred and fifty Pound of blood.

It is to be observ'd, that these Proportions of the thickness of the Coats of the *Vessels* to their Cavities were taken when the *Vessels* were empty, and consequently when the Coats were thickest, and the Diameter least, for all the *Vessels*, especially the Arteries, shrink and contract when they are empty. Let us suppose the Diameter of the *Cavity* of the Artery which was 0.407, to be increased 0.1. the Square of this *Cavity* would be 0.257049, and consequently the blood would be to the solid part of the body, as 2.7 to 1. If the Diameter were increased 0.2 the blood would be to the *Vessels*, as 3.9 to 1. If 0.3, it would be as 5.3 to 1. From these Proportions one may judge more exactly to what

How the Bulk of the Blood encreases upon a small encrease of the Diameter of the Blood-Vessel.

Degree the blood is heated or rarified in inflammatory Feavers, by the Largeness of the Pulse : As also how small a Quantity of blood must be thrown out at the Heart every Systole in languid Feavers when the Pulse is small.

*How the
Arteries
may be di-
lated in
Aneu-
rysms.*

It is surprizing to see how little the encrease of the Diameter of the *Cavity* of the Artery diminishes the thickness of its Coats ; for if we add to the Square 0.257049, the annular Space which we found to be 0.093432, then 0.350481 is the Square of the Diameter of the whole Artery, that is both of its *Coats* and *Cavity*. The Square Root of this Number is 0.592, from which if we subtract the Diameter of the *Cavity*, there remains 0.085, the half of which 0.0425 is the thickness of the *Coat* of the Artery. Thus I find that the Dia-
meter

meter of the *Aorta* may be encreased eight times its first bigness before its *Coats* become so thin as the *Coats* of the *Cava*. This shews how prodigiously *Aneurisms* may dilate the *Arteries* ; and how, when a large *Trunk* of an *Artery* in the *Arm*, *Leg* or *Thigh* is tied, the small *Arteries* (which all communicate with one another) may dilate to carry on the *Circulation* of the *Blood*.

The next sort of *Vessels* I come to consider is the *Fibres* of the *Muscles*, which tho' they may be more bulky, yet they cannot be more numerous than the *Arteries*; for every *Fibre* must have at least one *Artery*, and it is probable it has several. They without doubt have considerable *Cavities*, being they swell, are blown up, and thereby considerably shortned when

Of the
Quantity
of the blood
in the Fi-
bre of the
Muscles.

the Muscles act. And their sides can be but thin, or else they could not be distended by so small a Force. Besides the Blood appears as plainly thro' them as it does thro' an Artery of an equal bigness, and therefore we cannot judge their sides to be thicker than the Coat of an Artery of an equal bigness. The Proportion of the thickness of their sides to their Cavities is not to be taken after the Manner we have done those of the Veins and Arteries, but that we might make some Estimate of it, I made the following Experiment.

I took a piece of the Intestine of a Dog, with part of the Mesentery and *Pancreas Asellii*, and having carefully emptied it of all its Contents, I weighed it exactly with all the Blood in the Vessels, its Weight was one Ounce and a half,
one

one Drachm and eighteen Grains ; then I injected warm Water into the Artery, and having sufficiently washed out all the Blood, I blew it up, and hung it up to dry in the Shade ; after it had dried about a Week, I weighed it again, and its Weight was two Drachms, two Scruples, and eleven Grains : By which it appears, that it had lost six hundred and thirty seven Grains, and that there remained only one hundred and sixty one Grains. Now this Loss could be only of the Fluids, which being diluted with the warm Water, were the more easily evaporated, and therefore if the Blood in every part of the body bore the same Proportion to the solid Part, that it does to the solid Part of the Intestines, their Proportions would be 3.9 to 1, and a body weighing one hundred and six-

ty Pound would contain one hundred and twenty seven Pound of *Blood*, so that even the Fibres of the Muscles are less solid than the Arteries. But the Fibres which perform the Peristaltick Motion of the Intestines, are not so spongy as the Fibres of the Muscles, for we find them firmer and harder; besides, if we consider that the Peristaltick Motion is performed by a very small Contraction of the Fibres, for which a very small Inflation will suffice; but the Contraction of the Fibres of the Muscles being great, they must be considerably inflated, and consequently more spongy, and capable of receiving a larger quantity of *Blood*, than the Fibres of the Intestines; and therefore it is evident, that in the Muscles which make up far the greatest part of the Body, the Proportion of the *Blood*
to

to the solid Fibres must be above 3.9 to 1, or almost as 4 to 1.

To know what Proportion the Fluids of the Nerves bear to the solid Part of the Nerves. I dried a piece of the *Medulla Spinalis* without any Art or Preparation, excepting the flitting of it, and I found that it lost near $\frac{3}{4}$ ths of its Weight, so that it appears, that even the Nerves are not more solid than the other Parts. And as to the Lymphatick *Vessels*, I believe every one will easily agree, that the Fluids in them bear a much greater Proportion to their Coats, than what has yet been found.

Of the Quantity of Fluids in the Nerves.

The Bones of all the Parts in the Body seem to bid the fairest for Solidity, and yet even their Fibres are not without their circulating Juices, what else is the *Callus* which unites and cements the Extremities

Of the Quantity of Fluids in the Bones.

of broken *Bones* ? In it there are no Fibres, nor Parts to be distinguished, but it appears like an uniform inspissated Juice. At whatever Time or Age the Misfortune of a broken *Bone* happens, this Juice is always at hand, which shews, that it is always circulating, tho' slowly : If it stagnated, it would harden, as it does when it is extravasated, and forms a *Callus* ; and consequently all the Passages being obstructed, no broken *Bone* could unite. This Juice is like to the viscous Sap of Trees ; for without doubt a Fluid may move as easily thro' the Fibres of the *Bones*, as thro' the Fibres of an Oak. The Excrescencies of the very Substance of the *Bones*, their Nodes, Swellings, and softening like Wax, of which there are several Instances to be found in Authors, even of Persons

sons grown in Years, do sufficiently evince a fluid circulating thro' their Fibres. No doubt but that the older we grow, the narrower are the Channels of the Fibres, the viscid Fluid hardening towards their Sides, and after Death intirely obstructing them, so that the whole Fibre appears solid; but still it is really no part of the Fibre, no more than the Crust with which some Waters line the Pipes thro' which they run, is part of the wooden or leaden Pipe, or the Glew in which a Sponge has been soaked, can be said to be part of the Sponge: And as these may be taken out, without taking away any of the Substance in which they are contained, so likewise may this Fluid in the *Bones*. What else is the Jelly made of Harts-horn, but a Fluid extracted by boiling Water, the

the Fibres and Substance of the Horn still remaining undissolved? Is not the Jelly extorted by *Papin's* Digester out of dry and solid *Bones* the same Fluid? That I might know what Proportion it bears to the Fibres of the *Bones*, I caused the *Bone* in the Knuckle of Beef, being first boiled, and the Marrow taken out, to be put into the Digester. Before it was put in, it weighed 22 Ounces $6\frac{1}{2}$ Drachms, when it was taken out and dried, it weighed 11 Ounces $1\frac{1}{2}$ Drachm, so that it lost above half its Weight, and yet the Texture of the smallest Fibre in the most spongy Part of the *Bone* was not broken, and the middle or more solid Part appeared to be made of Parallel *Laminae*, of which four or five would hardly exceed the thickness of a Sheet of Paper. And I doubt

doubt not but that if the Experiment had been made upon younger *Bones*, but that the Proportion of the Fluids to the solid Part would have been found to be much greater. Now if the *Bones* contain such a quantity of Fluid, what do the *Tendons*, *Membranes*, *Ligaments* and *Cartilages*, which are much softer Substances, and which upon boiling likewise yield a Jelly? And is not Glew which is extracted out of the Skins of Animals such a sort of Fluid? So that it is highly probable, that there is not a Fibre in the whole Body, in which some Fluid or other does not circulate, but which hardening after Death, and perhaps some part of it before, no Elixation whatsoever can extract.

Thus have I consider'd the several sorts of Substances in the Body, and shewn what Proportion the Fluids

The Coats of the Vessels composed of other Vessels.

Fluids in each of them bear at least to their solid Parts, I say at least, for no Preparation nor Art can extract a Fluid so viscid, and so apt to harden, as the *Blood* is, out of the innumerable Meanders of such infinitely small *Vessels*. I have also supposed the Coats of the *Veins* and *Arteries* to be perfectly Solid, that is, without Fluids, whereas it is evident to the naked Eye, and agreed on by all *Anatomists*, that they are composed of *Myriads* of *Veins* and *Arteries*. What an innumerable company does an Inflammation of the Eye shew upon the *Tunica Conjunctiva*, and are there not many more to be discovered by *Microscopes*, and the finer the Glasses are which we use, still the more *Vessels* we discover, so that if we can see no more, it is only because our Glasses are not better. Who-
foever

soever is acquainted with the Preparations of the curious Dr. Ruysck would be apt to believe that the whole Body, and all its Fibres were nothing but *Blood-Vessels*.

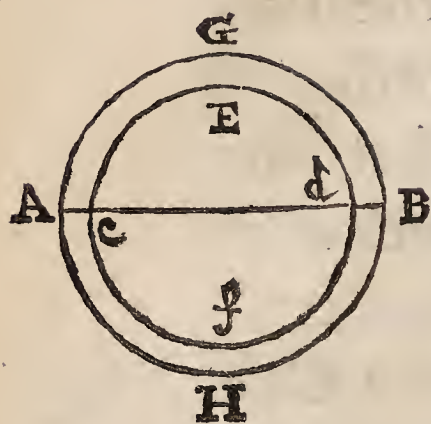
A piece of the *Aorta* of a Calf weighed 240 Grains, when dried, it weighed 80 Grains; so that from this Experiment it appears, that the *Blood* in the Coats of the Arteries is to the Coats as 1.7 to 1, which is the same Proportion the *Blood* in the great Arteries bears to their Coats, and yet we cannot suppose that any more than the thin part of the *Blood* was exhaled.

The quantity of Fluids in the Coats of the Arteries determined by an Experiment.

Now therefore, supposing that the *Vessels* are made up of others, full of Fluids, and that there is the same Proportion of the Fluids to the solid Parts in each of them, the Quantity of *Blood* in the Body

A general Method to determine the Quantity of Fluids in the Coats of the Vessels.

may



may be thus determined. Let the Annular Space $GABH$, Ecd , be to the whole Circle $AGBH$, as 1 to a ; then in a Body composed of such Vessels filled with Fluids, the Fluids will be to the Solids (if the Annular Space is solid) as $a - 1$ to 1. But if this Annular Space is likewise composed of the same sort of Vessels, then in the whole Body the Fluids will be to the Solids as $a^2 - 1$ to 1: and again, if these lesser Vessels are composed of others still less than themselves, then the Fluids will be to the Solids, as $a^3 - 1$ to 1: and if there should be four such Orders of Vessels, the Fluids will be to the Solids, as $a^4 - 1$ to 1: if five, as $a^5 - 1$ to 1: if six, as $a^6 - 1$ to 1: so that the Proportion of the Fluids
to

to the Solids may be increased in *Infinitum*. In the Arteries *a* is equal to 2.7, in the *Veins* it is equal to 16.6, and according to the several Series of *Vessels*, the *Blood* will be to the solid Part of the *Body* in these Proportions.

1,7		15,6	
6,2		274,5	
18,6		4573	
52,1	to 1	75932	to 1
142,4		1250492	
286,4		20758082	

If the *Body* is composed of *Vessels*, whose Coats are made of other *Vessels*, and these again of others, as has been said; then the *Bodies* of the *Animalcula* in *semine*, or the *Prima Stamina vitæ* may be increased to any bulk, and the Coats of the *Vessels* so far as we can

That all the Solids in an animal Body at full growth may be no more than what was in the Animalcula in semine.

can discern, grow thicker and thicker, without the Addition of any Substance to the *Vessels*, only by increasing the Quantity of Fluid, with which they are filled. For as the large *Vessels* swell, so likewise must the small ones, of which their Coats are composed down to the very last, and the swelling of the several Orders of *Vessels* must necessarily increase the thickness of the Coat of that *Vessel* which they compose; so that by increasing the Number of the Orders of the *Vessels*, the Coats of the first Order of *Vessels* may be increased to any Degree, and yet the Diameter of the *Vessels* which compose these Coats, not greater than a given Line.

That the Coats of the great *Vessels* are composed of smaller *Vessels*, is Matter of Fact, and we know nothing to the contrary, but
that

that these small Vessels may be composed of others still smaller than themselves. We know not how many *Laminae* or *Folds* there are in any Membrane of the Body. That excellent Anatomist Mr. *Cowper* informs us, that every Membrane is Vesicular, and may be blown into innumerable Cells. That transparent Membrane the *Cornea* of the Eye consists of as many parallel *Laminae*, as the nicest Hand of the most expert Anatomist can raise. That delicate thin Membrane which involves the *Brain*, divides its self into two *Laminae*. And it is very probable, that the *Hydatides*, of which several are found within one another, are nothing but the Coats of the Lymphatick Vessels, distended and separated by the Lympha, and yet it is hard to conceive any thing thinner than the Coat of a

K

Lym-

Lympheduct, which is not visible but when it is distended with Lympha. If we know not the Number of *Laminae* which compose the Membranes, how can we reckon the Number of Fibres, of which the *Laminae* consist? Or how should we discover the Number of Fibres, of which each Fibre is made up? *Leeuwenhoeck* tells us, That the Fibre of a Muscle which was nine times smaller than a hair of his Beard was made up of a hundred smaller Fibres, and yet each of these must have had Nerves, Veins and Arteries, and perhaps each of them made up of a hundred more: For of how many Series of Vessels any one Vessel is made up of, is what no Microscope can discover; because only one Order can lie at a time in the *Focus* of the Glass, and if
more

more could, their several Refractions would confound the Sight.

If all the solid part of the Body was contained in the *Animalcule*, then *Accretion* and *Nutrition* are nothing but the Repletion and Distention of the Vessels, and it is easie to conceive how *Helmont's* Tree grew from five pound Weight in five Years time, to one hundred and sixty nine Pound, only by the Addition of Water: Nor does this at all contradict the Ingenious Doctor *Woodward's* Experiments concerning Vegetation, but his Experiments are rather a Confirmation of this Doctrine. For the fewer Terrestrial Particles are contained in the Water by which any Plant is nourished, the quicker the Water passes off thro' the Pores or Excretory Ducts of the Plant, and con-

K 2

sequent.

frequently the less the Vessels are distended ; but if the Water is impregnated with a large quantity of terrestrial Matter, it cannot pass off quickly, but being retained in the Plant, the vessels must be distended, and consequently the Bulk of the Plant increased. That the fewer terrestrial Particles the Water contains, the quicker it passes off, is evident from Experiments : for two Plants of Mint, near of the same Weight, set at the same time, the one in Rain-Water and the other in Thames-Water (which is more copiously stored with terrestrial Matter) this did thrive to almost double the bulk of that, and with a less Expence of Water ; yet the Experiments do sufficiently evince, that Plants require a proper Nourishment, as well as Animals, without

without which they can never kindly thrive. For Life is continued, and all its Functions performed by the straining off of several sorts of Juices from the common Fluid, which in Animals is called Blood: But if this common Fluid cannot afford these Juices, or is not fit to be turned into them, then that Body whether vegetable or animal, must turn sickly, and at last die. Some sorts of Water are more easily transmuted into the Juices of some Plants than others, for we see some love a very dry and some a very wet Soil, and some will grow in Water alone, and therefore it was that *Helmont's Willow Tree* grew to such a Bulk.

If the most proper Food can only distend but not increase or add to the Substance of the solid Part of

No equivocal Generation.

the Body, how much more reasonable is it to suppose, that no Matter, howsoever disposed, can at first frame these solid Parts, without an Omnipotent Power immediately actuating it.

The Possibility of the Resurrection of the same Body

And does not all that has been said demonstrate not only the Possibility but likewise the great Probability of that Supposition, which the Reverend and Learned Mr. *Clark* uses to show the Possibility of the Resurrection of the same Body ; for if all the solid Parts are no more than the Original *Stamina*, and all Nourishment only a Fluid in a perpetual Flux, then no Part of an animal Body can become Part of another animal Body ; but the Body is always the same, from the first Moment of Life to the last.

But

But whether the Coats of the Vessels are composed of others, or not, the Experiments I have brought do clearly demonstrate that the Fluids in the Body are to the Solids at least as 3.9 to 1, and therefore in a Body weighing one hundred sixty pound, there must needs be one hundred twenty seven pound of Blood. From which Quantity that I may put the matter out of all manner of Dispute, I shall deduct the Weight both of the Fat and Bones, tho' I think that some Arguments might be alledged to prove that even the Fat circulates, and I have already shown that there is a Fluid in the Bones.

*The Weight
of the Fat
and Bones
deducted
from the
Quantity
of Blood.*

In a Body weighing one hundred sixty pound, I shall suppose that the Fat is an Inch deep all round the Body, and in such a mean Weight, I believe this will be suf-

ficient to answer for all the Fat every where else. Dr. *Wainwright* reckons the Surface of the Body measures fifteen square Feet, and therefore the Fat must be one hundred eighty cubick Inches. Now a cubick Inch of Fat weighs about half an ounce or something more, and therefore the whole Fat of the Body of a Man weighing one hundred sixty pound is ninety ounces, or five pound ten ounces; but I shall suppose it to be seven, and that the Bones weigh twenty pound, and there remains one hundred pound for the Quantity of Blood in a Man weighing one hundred sixty Pound.

*Concerning
the Velocity
of the
Blood.*

Having in the first Treatise spoke of the Nature and Quality of the Blood, and in this of its Quantity; it will not be improper in this Place to say something

thing concerning its absolute Velocity.

All who have wrote of the Velocity of the Blood since the Discovery of its Circulation by the immortal Dr. *Harvey*, have contented themselves only to calculate the Quantity which passes through the Heart in some determined Time: But none has as yet given us the absolute Velocity with which it is thrown out of the Heart, runs through the *Aorta*, or any of its Branches. Many have indeed spoke of the rapid Motion of the Blood, and that it must be much greater near the Heart than in the Extremities; but how much greater it is in that than in these, or whether it moves through the *Aorta* at the rate of 5, 10, 100, or 1000 Feet in a Minute, is what has never as yet been determined; tho' next to the

Circu-

Circulation of the Blood its self, it seems to be a thing of the greatest Moment for explaining of the animal Oeconomy. After the Motion of the Blood was once determined, methinks it was but natural to have enquired in the next Place with what Degree of Velocity it mov'd.

The Velocity of the Blood in the *Aorta* may be thus determined.

The Velocity of the Blood in the Aorta.

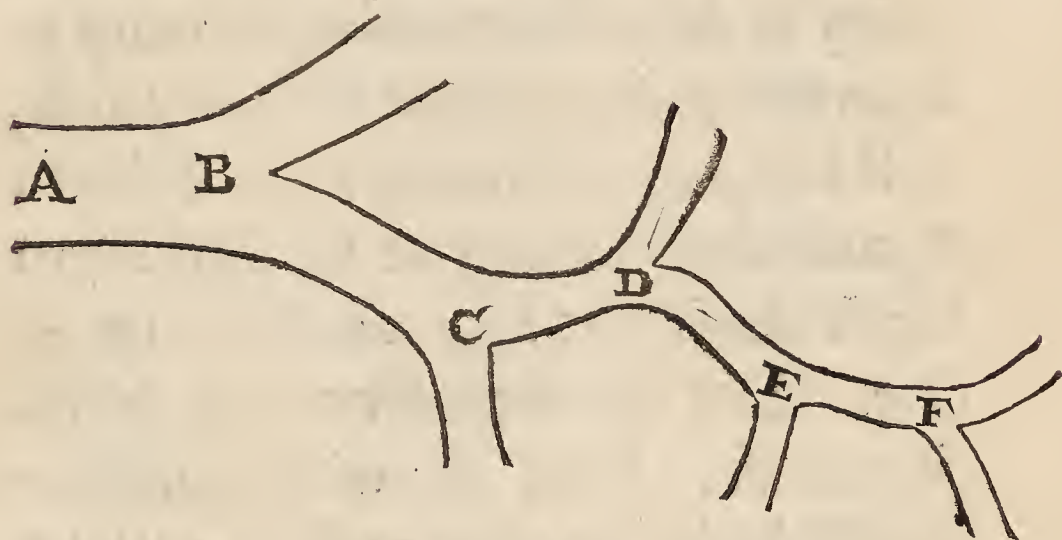
The Velocity with which a Fluid flows out of any Orifice uniformly and always running in the same Quantity, is equal to the Velocity of a Body which describes a Space of the same length with that of a Cylinder whose Base is equal to the Orifice, and whose Magnitude is equal to the Quantity of the Fluid that runs out in the same time, as 'tis evidently shown in the *Lectiōnes Physicæ* Jo. Keil, pag. 114. Now suppose

suppose the Heart contracts eighty times in a Minute, and that each Contraction throws into the *Aorta* one Ounce of Blood. An Ounce of Blood is equal in bulk to 1, 659 inch, and consequently 80 Ounces are 132, 72 inches. The Diameter of the *Aorta* in a middle siz'd Man, I have found to be 0, 73 Parts of an Inch, and therefore its Orifice is 0, 4187, by which divide 132, 72, the Quotient 316 inches or 26 feet gives the length of the Cylinder, or the space through which the Blood will go in a Minute, supposing it were constantly going out of the Heart with the same Velocity: But because of the *Diastole* of the Heart, which is at least half the time of a Pulsation, there goes out 80 Ounces in half a Minute, and consequently the Velocity of the Blood is at least twice
as

as great, or such as will make it to move at the rate of 52 Feet in a Minute : I have supposed that the Quantity of Blood that the Heart throws out every *Systole* is only one Ounce ; because that (being allowed of by all) gives the least Velocity, and we are sure it is at least so much ; but if every *Systole* throws out two Ounces, as many do suppose, then the Velocity is double to what it has been here determined.

If the sum of the Sections of the Branches of the Arteries were always equal to the Section of their Trunks, and if the Circuits in which the Blood moves were every where equal, the Velocity of the Blood would be every where the same it has been determined to be in the *Aorta*. But we find that the sum of the Sections of the Branches do
every

every where exceed the Section of their Trunks, and therefore the Velocity of the Blood must decrease as the Number of Branches increase. Now let us suppose that the sum of the Sections of the Branches, bears every where the same Proportion to their Trunks, and



suppose A the Trunk of an Artery, and that at B it divides into two Branches, and the Branch B likewise into two at C, and that again into two at D, and so on: call A the Section of the Artery, the sum of the Sections of the Branches at B call B, and those at C

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let

let them be named C, and those at D, E and F call also D, E and F. Let the Section of the Canal or Branch B C, be to the Section of the two Branches at C, as A is to B. Likewise the Section of the Canal C D to the Section of the two Branches at D, as A to B, &c. Then the Velocity at A, will be to the Velocity at B, as B is to A, and the Velocity at B, will be to the Velocity at C as B is to A, and the Velocity at C, will be to the Velocity at D, as B is to A, &c. Let A represent the Velocity at A, then $\frac{A^2}{B}$ will represent the Velocity at B, and $\frac{A^3}{B^2}$ will be the Velocity at C; the Velocity at D will be $\frac{A^4}{B^3}$, that at E will be $\frac{A^5}{B^4}$, that at F will be $\frac{A^6}{B^5}$: and if the Artery be divided into a hundred such Branches before it come to the smallest, the Velocity at the last of them will be $\frac{A^{101}}{B^{100}}$, if into a thousand

land, the Velocity at the last of these will be $\frac{A^{1001}}{B^{1000}} = A \times \frac{A^{1000}}{B^{1000}} =$ to the thousandth Power of $\frac{A}{B}$ multiplied by A : The Velocity therefore at A , is to the Velocity after a thousand branchings, as A is to $A \times \frac{A^{1000}}{B^{1000}}$, that as is 1 to $\frac{A^{1000}}{B^{1000}}$ or as 1 is to the thousandth Power of $\frac{A}{B}$.

Thus if the *ratio* of A to B was known, the Velocity of the Blood at the several branchings of the Arteries might easily be determined; but this is only to be found by measuring of the Arteries, and by the Measures which I have formerly taken I find the *ratio* in different Places to be very different. I wish those who have more Leisure and Opportunity, would measure the Circumference of an Artery injected with Wax, both above and below each Division, by which means we might come to a greater
Certainty

Certainty in this Matter. The most general Proportions of the Trunks to their Branches that I have found are as 41616 to 43506 and as 41616 to 52126: Now if we take the first of these Proportions, $\frac{A}{B}$ is 0.9565, whose Logarithm is 9.9806850: This Logarithm multiplied by 30, gives the Logarithm of the 30th Power of 0.9565: Now the Logarithm 9.9806850 multiplied by 30 is the Logarithm 9, 4205500, to which the Number answering in the Tables is 0.26336. That is the Velocity at A in any Artery, is to the Velocity at the 30th branching as 1 to 0.26336, or as 100000 is to 26336 which is almost as 4 to 1: The Logarithm of 0.9565 multiplied by 100 gives for the Logarithm of the Velocity at the 100th branching 8.0685000,

the

the Number answering to it in the Tables is 0,011708: Hence the Velocity of the Blood in the *Aorta* is to the Velocity in the hundredth Division as 1 to 0.11708, or as 1000 000 to 11708, that is, it will be almost an hundred times greater. But if we suppose that the Artery divides a hundred times before it comes to the smallest Capillary or evanescent Artery. The Logarithm of the thousandth Power of 0,9565 is 80.6850000 whose Number is 0,0000 000 000 000 000 484, and consequently the Velocity in the *Aorta* will be to the Velocity in its last branches in a greater Proportion than 10000 000 000 000 000 000 to 1.

If the Proportion between the Trunk of an Artery and its Branches be taken to be as 41616 to 52126,
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then

then $\frac{A}{B}$ is 0, 7983; and at the hundredth Division the Velocity of the Blood in the Trunk will be to the Velocity in the Branches as 10 000 000000 000 to 16466. At the 200th division as above 10 000 000 000 000 000 000 to 1 : At the 400th it will be as 10000 0000 00000 00000 00000 00000 00000 00000 to 1. Thus having shewn how the Velocity of the Blood may be determined at each branching of the Artery, our next enquiry must be to find out how many times an Artery may divide before it becomes the smallest Capillary, which may be thus done.

Suppose the *ratio* of the Trunk to the Branches to be as $r : s$. and call the Trunk c , then $r : s :: c : \frac{sc}{r}$ which is therefore the sum of the two first Branches, and each Branch is $\frac{sc}{2r}$ again $r : s :: \frac{sc}{2r} : \frac{s^2c}{2r^2}$ this is the sum

sum of the second branching, of which $\frac{1}{2}$ is the Branch $= \frac{s^2 c}{4r^2}$, and just so the third Branch will be $= \frac{s^3 c}{8r^3} =$ to the Cube of $\frac{s}{2r}$ multiplied by c.

Now if we call the number of branchings x , and $\frac{s}{2r} = d$, the last Branch will be $d^x c$. Let us suppose the smallest Artery has its Diameter $\frac{1}{100}$ part of a Hair's Breadth, and that the Diameter of a Hair is the $\frac{1}{200}$ part of an Inch, the Section of this Artery will be 0,000 000 00 25, which I shall call $= e$. Then we have this Equation $d^x c = e$, which expressed by Logarithms is $x \times \text{Log. } d. + \text{Log. } c = \text{Log. } e$, and $\frac{\text{Log. } e - \text{Log. } c}{\text{Log. } d} = x$.

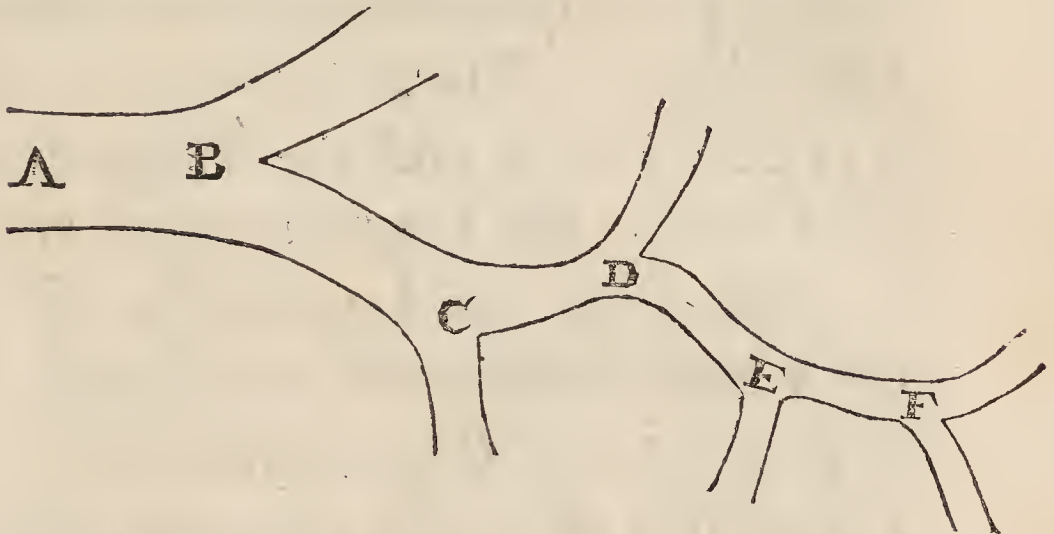
Let us take the Proportion between the Trunk and the Branches to be as 41616 to 43506 :: $r : s$, then the Logarithm of s divided by $2r$ is — 0.2817412 = Logarithm

rithm of d , it being equal to the Logarithm of s minus the Logarithm of $2r$: The Logarithm of e is -8.6020600 , and supposing c equal to the Diameter of the *Aorta* equal to $0,5329$ Decimals of an Inch, its Logarithm is -0.2733543 , and the Logarithm of e minus the Logarithm of c is $-8,3287057$, this divided by $-0,2817412$ gives in the Quotient something less than 30 for the Number of branchings between the *Aorta* and the smallest Capillary, and consequently the Velocity of the Blood in the *Aorta* is about four times greater than it is in the last Division of the Artery.

But this number of branchings is undoubtedly too few, if we consider the number of Arteries it produces for the whole Body.

For

For at F the number of Branches are 2, at E 4, at D 8, at C 16, at B 32, and therefore at 30 the



number of Arteries in the whole Body will be the 30th Power of 2 which is 1073 000 000, a number which must be prodigiously short of the true number, if we consider that every Fibre of a Muscle, and every Vesicle of a Fibre is nothing but a Net-work of Blood Vessels. The *ratio* therefore of the Branches to their Trunks must be much greater than 41616 to 43506, and in fact we do frequently find it greater. Let us therefore see what the

number of Branchings will be from the other *ratio* of 41616 to 52126, which is almost as frequent as the first, especially at some distance from the *Aorta*: Then 41616 is to 52126 :: $r : s$. and the Logarithm of s *minus* the Logarithm of $2r$ is $-0.203237 =$ Logarithm of d , by which number if we divide $-8.3287057 =$ Logarithm of $e -$ Logarithm of c , the Quotient gives for the number of branchings above 400 and consequently the greatest Velocity of the Blood will be to the least in a greater Proportion than 1000 00000 00000 00000 00000 00000 00000 00000 to 1.

Thus we see how prodigiously the Velocity of the Blood decreases as the number of branchings encrease; and tho' perhaps we have not taken the exactest *ratio* of the
Branches

Branches to their Trunks; yet whenever that shall be known, the Method we have here used, is that whereby the Velocities at the several branchings may be determined. This much I am assured of, the last *ratio* of the Branches to their Trunks falls much short of what I have found in several Places of the Body, and I am apt to think that the *ratio* encreases every Division from the great Arteries. Some nice and exact Measures of the *Vessels* taken after the manner I have proposed would give us a certain Knowledge of this part of the animal Oeconomy.

But till this exact *ratio* is discovered, let us suppose the least Velocity to be as we have calculated it at the hundredth Division only that is 10000000000 times less than it is in the *Aorta*; then when

the Blood in the last Division of the Artery moves one Foot, that in the *Aorta* moves 10000000000; now the Blood in the *Aorta* moves at the rate of 52 Feet in a Minute, and consequently it moves 1000000000 Feet in 13354 Days, in which time the Blood at the hundredth Division moves only one Foot, or it would be 278 Days in moving of a Quarter of an Inch, if the last Branches were so long: But if the least Velocity is at the seventieth Division, the Blood will move there at the rate of a Foot in about thirteen Days: And at the fiftieth at the rate of a Foot in three Hours.

As between the greatest and the least Velocity we are to conceive all the intermediate Degrees; so we are not to imagine that in every evanescent Artery there is the least Velocity, but only in such as have an hundred

dred Divisions between them and the great Artery, and the Velocity of the Blood in the evanescent Arteries is every where proportionable to the number of Divisions between them and the great Artery; and therefore in all the small Arteries which come immediately from the *Aorta*, and which after a few Divisions transmit their Fluid to the Veins, the Velocity of the Blood is but a little diminished.

From all this it appears that when the whole Mass of Blood is to be altered, that the Course of Physick ought to be continued for a long Space of time, being the Blood moves slower and slower the farther it moves from a great Artery, and consequently it must be a great time before the whole Mass of Blood can be mixt with the alterative Medicine. And being the

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Circulation of the Blood through Glands which receive Arteries immediately from a great Vessel, is very quick, they may carry off a great Proportion of the Medicine in a very little time, and therefore it is not the taking of great Quantities, but a constant taking that can alter the Mass of Blood; and from hence it follows that when the Blood is to be altered by mineral Waters, which are apt to pass through the Glands of the Kidneys, that they ought not to be drunk in large Quantities: For if they pass off, they have not the designed Effect; and if they do not, being drunk in a little time, they mix but with a small Quantity of Blood, which must disorder the animal Oeconomy.

Of Muscular Motion.

A Muscle is a Bundle of thin and parallel Plates of fleshy Threads or Fibres, enclosed by one common Membrane: All the Fibres of the same Plate are parallel to one another, and tied together at extremely little distances, by short and transverse Fibres. The fleshy Fibres are composed of other smaller Fibres enclosed likewise by a common Membrane: Each lesser Fibre consists of very small *Vesicles* or Bladders into which we suppose the Nerves, Veins and Arteries to open; for every Muscle receives Branches of all those *Vessels*, which must be distributed to every Fibre. The two Ends of each Muscle, or the Extremities of the Fibres, are
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in the Limbs of Animals fastened to two *Bones*, the one moveable, the other fixt, and therefore when the Muscles contract, they draw the moveable *Bone* according to the Direction of their Fibres. When the Muscles contract in length, they swell in thickness, as may be perceived by laying the Hand upon the *Masseter* a Muscle of the lower Jaw, and pressing the Grinders together: but this Power of contracting or swelling is lost when either the Artery or Nerve of the Muscle is cut or tied, and therefore we conclude that the Contraction, Swelling, or Motion of the Muscles is performed by the *Blood* and *Animal Spirits* distending the *Vesicles* or Cavities of the Fibres. This Distention of the *Vesicles* of the Fibres must be either by their being filled with a greater Quantity
of

of *Blood* and animal Spirits than they were before the Contraction, or the *Blood* and Spirits mixing must rarifie, and fill up a greater space.

That the *Vesicles* of the Fibres are not distended purely by the Quantity of *Blood* and Spirits will appear if we consider, that were the *Vesicles* distended only by the Quantity of Fluids contained in them, Nature (whose Operations are always the most simple) had only used one Fluid and not two; for in the Works of Nature we nowhere find two necessary Causes where one could have produced the same Effect: Now how small soever we suppose the Quantity of Fluid brought by the Nerves to the Muscles, that alone might have contracted the Fibres (if a Quantity only of a Fluid had been requisite)
by

by dimishing the Diameters of the Cavities or *Vesicles* of the Fibres, as will appear by the sequel of this Discourse. And as it is evident that the reason why the Spirits alone do not distend the *Vesicles*, is not that there is not a sufficient Quantity for that purpose; so it will likewise appear that if there had not been a sufficient Quantity of the nervous Fluid, yet the Quantity of Blood could have given no assistance in the Distention of the *Vesicles*; for if the *Vesicles* contain a greater Quantity of *Blood* when the Muscles contract, than they do when the Muscles are relaxed, this Augmentation must proceed either from the *Bloods* being stop'd in the *Vein*, or it must move suddenly with a greater *Velocity* thro' the Artery into the Cavities of the Fibres. If the *Blood* is stopp'd in
the

the *Vein*, it must be by the Contraction of its Coats, or by some external Pressure upon them : If by the Contraction of the Fibres which compose the Coats of the *Vein*, the same difficulty remains to be explained, for whatever is the cause of the Contraction of the Fibres of a *Vein*, will likewise serve to contract the Fibres of a *Muscle*. If the *Blood* is stopp'd in the *Veins* by a pressure upon their Coats, it must be by the swelling of the Artery or Muscular Fibres. If the Artery swells and presses on the *Vein*, the Circulation of the *Blood* must be intirely stopp'd; for that Pressure will constantly encrease, the *Blood* being still accumulated in the Artery, and therefore it will for ever hinder all Passage through the *Vein* : If it be said that the *Blood* moving sometimes with a greater *Velocity* through

s

through the Artery into the Cells or *Vesicles* of the Fibres, will distend them ; this greater *Velocity* must proceed from the force of the Heart, from which alone the *Blood* derives all its Motion : Now if the Heart acts with a greater force it will encrease the *Velocity* of the *Blood* universally throughout the whole *Body*, and each Muscle and its Antagonist will be thereby equally contracted, and consequently neither will contract. And therefore being both the *Blood* and Fluid of the Nerves are necessary to the Contraction of the Muscles, and being the Contraction is not performed by the Quantity of these Fluids, it remains only that by their Mixture, they rarifie and distend *Vesicles*.

Now for the explaining of this Rarification of the *Blood* and Spi-
rits

rits in the *Vesicles* of the muscular Fibres, let us suppose a small Globule of Air between the Particles of a Fluid, and that the Particles have a strong attractive force by which they endeavour to come together, they pressing every way equally on the Globule of the Air, will hinder it from escaping any way from between them; but the force by which they endeavour to come together, being prodigiously greater than the force of their Gravity, they will by this force produce a very considerable Condensation of the Globule of Air that lies between them, and the force of Elasticity being proportional always to its Condensation, the force by which this airy Globule will endeavour to expand its self, will likewise be vastly great; and consequently if by any means this *Nisus*

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of

of the Particles of the Fluid to come together should be taken off, the Air between them would expand its self with a very considerable force. Now if upon the mixing of another Fluid the Particles of the first Fluid should be more strongly attracted to the Particles of this other Fluid, than they were before to one another, then would their *Nisus* to one another cease; and they would give the Globule of Air that is between them, liberty immediately to expand it self; and the whole Fluid would take up a greater space than it did before. But when the Particles of the two Fluids come to be united together, they will again enclose the Globule of Air that lies between them, and by their mutual Attraction soon bring it to its former State of Condensation.

Now

Now that the *Blood* contains a great number of Globules of Air is evident from the Quantity it yeilds in the Air Pump. And that the Particles of the *Blood* have a strong attractive force is likewise plain from what has been said in the Theory of Secretion. By this Attraction of the Particles, the Globules of the *Blood* are formed; and in viewing the Circulation of the *Blood* with a Microscope, I have sometimes observed, that where the Diameter of the Canal has been less than the Diameter of a Globule of *Blood*, that the Globule would be pressed into a Spheroidical Form, but when it came into a wider part of the Canal again it would immediately reassume its former Figure; which I think is probably owing to a smaller Globule of Air enclosed within, and expand-

ing its self equally every way, when the sides of its circumambient Shell of *Blood*, are not longer pressed by the sides of the Canal.

These Globules of *Blood* continually circulating through the *Vesicles* of the Fibres (which are probably capable of containing only one Globule at a time) meet with the Animal Spirits, which drop from the Nerves. Now the Minuteness of the *Glands* of the Brain, and the Smallness of the Fibres of the Nerves, plainly show that the *Animal Spirits* are a Fluid, consisting of the smallest Particles of any in the Body; and therefore their attractive Force must be the greatest of all the Particles in the Blood, as is evident from what Sir *I. Newton* has calculated about the Rays of Light; and consequently the *Animal Spirits* meeting with the Globules of the
M Blood

Blood in the *Vesicles* of the Fibres, and furrounding them, must attract the Particles of which they are composed, more strongly than they do another; and consequently their *Nisus* to one another ceasing, the condensed Globule of Air will expand its self with a very considerable force, whereby each *Vesicle* of the Fibre will be distended, and consequently the Fibre shortned, *i. e.* the whole Muscle will be contracted. But when the Particles of the Globule of *Blood* are mixed with the nervous Fluid, they will both together enclose the Globule of Air again and compress it into as small a space as it was before, and thus the Contraction of the Muscle must immediately cease; unless fresh Blood and Spirits still succeeding one another continue the Inflation of the *Vesicles*. But when a Muscle

has been strongly contracted for some time, the Quantity of Spirits spent, being more than can be discerned in the same space of time by the Glands which supply its Nerves, the Inflation of the *Vesicles* must fall, and the Muscle grow feeble and weak; whereas the Tonick Motion of the Muscles, being performed by the Spirits protruded only by the Quantity last discerned in the Glands, will constantly continue without any weariness.

After this manner I conceive the *Vesicles* to be distended without any Ebullition or Effervescence, and their Distention to cease without any Precipitation, or flying off of the aerial Globules through the Pores of the Muscles. For to this Attraction of the Particles of Matter is owing most of the *Phænomena*; for explaining of which, Philosophers have
4 been

been forced to have recourse to active and subtile Particles, which contrary to their own Principles they have made to move themselves every way, and to do what ever they had a mind should be done : But how these Particles came by so great an Activity was not at all to be accounted for from any of their Principles. Thus in explaining of Muscular Motion they make the animal Spirits to cut and pierce the Globules of Blood, and with their sharp Points to run them through and through, that the imprison'd Elastic *Aura* might be set at liberty ; which notwithstanding could not be effected, unless we suppose that Holes may be made in Fluid Globules, as in a Board, and that the Fluid Particles stand in a Heap, as the Waters of the Red Sea did. And when the Aerial Globule is

got loose, the Intumescence of the *Vesicle* cannot be asswaged, but by supposing the Elastick Globules now to have Strength to break through the Muscles and Skin to come at the external Air, tho' before they had not Power nor Subtilty enough to get through a thin Shell of Blood.

But I come now to show the Mechanism of the Fibres, or how excellently and wisely they are contrived for contraction: It is a known Experiment that a Bladder when it is blown up and distended as to its Capacity, but contracted as to its length, will by the force of Contraction, raise a Weight to some determined height. And if two Bladders joined together and communicating with one another were blown up, the Weight would be raised by Inflation twice the
4 space

space that one alone would do it ; because I suppose that both Bladders contract equally , and consequently the Contraction of both together will be double the Contraction of either. Three Bladders thus joined and distended will raise the Weight to triple the Height , and four to quadruple ; so that if there were a String of Bladders join'd together , of equal Bulk, and like Figures, the space through which the Weight wou'd rise, wou'd be proportional to the number of Bladders, or, which is the same thing, to the length of the String.

Each Fibre of a Muscle consisting of a Multitude of small *Vesicles*, resembles a string of Bladders ; and therefore the Contraction of the Muscle, is always proportional to the length of its Fibres. And being

ing, the greatest Contraction of the Fibres is always less than $\frac{1}{3}$ of their length (as shall hereafter be demonstrated) there was a necessity that the Insertions of the Muscles should be near to the Joints, not only to encrease the Velocity of the Parts moved ; but likewise that they might describe greater Arches round the Centers of their Motion : And hence it is that those Parts which describe the greatest Arches, are moved by the longest Muscles ; as the Hand round the Elbow which is bent by the *Biceps* arising from the *Scapula*, and the Foot round the Knee which is bent by the Muscles whose Originations are as far distant as the *Ischium*. If these Joints had been moved by short Muscles inserted at each end into the Extremities of the articulated Bones, the Arm and Leg had moved

ved but a little way, and the Arches the Hand and Foot had described about these Joints, had been to the Arches they describe now, as the length of the short Muscles had been to the length of the Muscles they have now. On the contrary, where the Joints have but a small Motion there the Muscles are short; thus we find that the Fingers are pulled sideways by the *Interossei*, the Thigh is drawn outwards, and obliquely by the *Quadrigemini* and *Obturatores*, which are all short Muscles, and most of the Muscles of the *Vertebrae* run between one *Vertebra* and the next. From hence it is evident that the Originations and Insertions of the Muscles, are every where the best that could be contrived.

The Vesicles of which the Fibres consist are extremely small, for tho' one

one large Bladder may raise a Weight as high as several small ones, yet the Quantity of Elastick Fluid used in the Inflation together, with the swelling of the large Bladder, will be much greater, than when a Weight is raised by a string of small ones. For suppose two Bladders of similar Figures, but the Diameter of the one triple of the Diameter of the other, then will the one require twenty seven times the Quantity of Elastick Fluid to expand it that the other does, and it will swell to twenty seven times the space; and yet three of the lesser Bladders joined together will raise the Weight to the same Height that the bigger one does, but with nine times less Expence of Elastick Fluid, and they will take up but one ninth Part of the space. By diminishing there-

therefore the Bigness of the Vesicles, and encreasing their Number, the force required to distend the Vesicles, and the Distention its self may be diminished in any given Proportion, and come at last to be insensible. Suppose a Bladder of a determined Bigness can raise a Weight a Foot; a hundred Bladders whose Diameters are each $\frac{1}{100}$ part of the former being blown up will raise the Weight to the same Height, but the force of Inflation and the swelling of all put together will be ten thousand times less than in the large one.

If a Weight of a determined Bigness can be raised to a certain Height by one Bladder, or one String of Bladders to which the Weight is tyed; twice that Weight may be raised by two such Bladders, or Strings of Bladders, and
triple

triple that Weight by three such Strings. And consequently the Weight a Muscle can raise, will be always as the Number of its Fibres, that is, as its Thickness supposing the Distention of the Vesicles equal. And the absolute Strength of one Muscle is to the absolute Strength of another, as their Bulks.

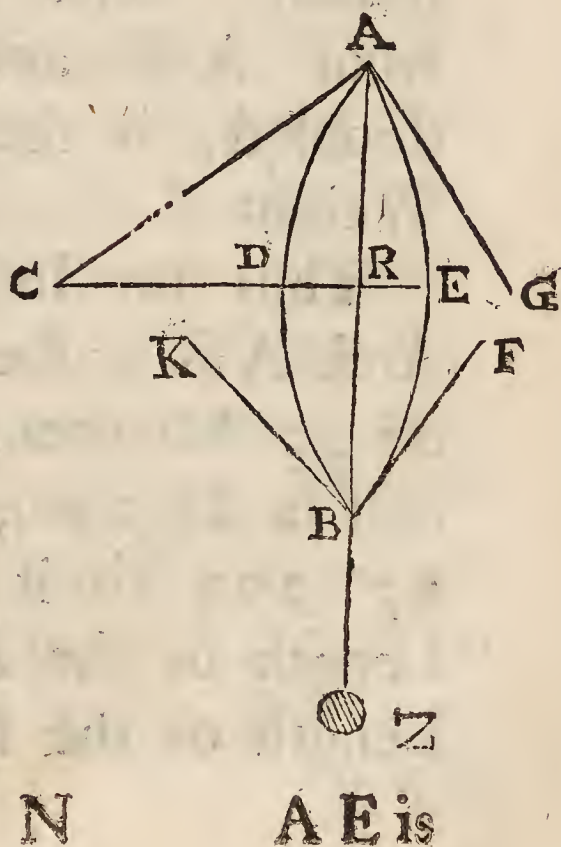
It is to be observed that in determining both the Contraction and Strength of a Muscle, no regard is to be had to the Tendons; because in them we observe no Inflation, and we find nature no where making use of a Tendon, but where either there was not room for the Insertion of so many fleshy Fibres, or where it was necessary the Muscle should draw from such a Point.

I shall in the next Place determine the force of the Elastick Fluid necessary

cessary to distend the Vesicles so as to raise to a determined Height any given Weight. But before this can be done, the Figure that each Vesicle will be formed into by the force of the Elastick Fluid distending it, must be found out; And therefore let us conceive each Vesicle to consist of an infinite number of Threads, whose Ends are fastened by transverse Ligaments; and from hence it follows that if a distended Vesicle were cut with a Plane thro' its Axis, the Curve of the Section will be the same with that of a Thread whose two Ends are fastened, and the whole pressed by an Elastick Fluid; and because Elastick Fluids endeavour to expand themselves every way, and all Fluids press perpendicularly on each Obstacle, it is evident

dent that the Thread must be every where equally and perpendicularly pressed, and therefore its Flexion or Curvature must be every where equal and similar, and consequently the Thread must be formed into a circular Arch. Hence it follows that the whole Secretion of the Vesicle consists of two equal and similar Arches, whose common Subtense is the Axis of the Vesicle. Suppose now AEB and ADB to be the two circular Arches, C the Center of the Arch AEB , AG and BF Tangents in the Points A and B , Z the resistance to be raised. The Angle CAG or CAE is equal to a right Angle $=$ to $CAR + ACR$, and therefore the Angle $ACR = GAR$, or $EAR = EBR = DBR$ and therefore the Arch EA or EB is the Measure of the Angle EAR ,
or

or $E B R$, and the Space through which the Resistance Z is raised is equal to the difference between the Arch $A E B$ and its Chord $A R B$, or equal to twice the Difference of the Arch $A E$ and its Sine $A R$, which having the Arch $A E$ or the Angle $E A R$ given in Degrees and Minutes may be easily calculated. But to do this the Length of the Radius $A C$ must be determined in such Parts, wherof 100000 make up the Arch $A E$ which is done thus. The Degrees of a circular Arch, whose Length is equal to the Radius of the Circle is $57^{\circ} 29' 5''$ and therefore the Degrees in the Arch



A E is to $57^{\circ} 295$ the Length of the Radius expressed in Degrees as 100000, the Parts of which the Arch A E consists, to the Radius expressed in the same Parts, which will therefore be given. And again, as the Tabular Radius is to the Tabular Sine of the Arch A E, so is the Radius A C (which is already found) to the Sine A R which will likewise be found. This being substracted from A E and the Remainder doubled, is the Elevation of the Weight Z.

Thus for Instance suppose the Arch A E or the Angle E B R to be 30 Minutes, say as $30'$, or half a Degree, that is $\frac{5}{12}$ is to $57^{\circ} 295$ so it is 100000 the Length of the Arch A E, to the Length of the Radius A C which will

will be found to be 11459000.
 And again as 100000 is to 872
 the Sine of 30° so is 11459000
 to A R which is therefore 99906,
 which subtracted from A E, and
 the Remainder doubled, gives 186
 the Sublevation of the Weight
 Z in such Parts whereof A E is
 100000.

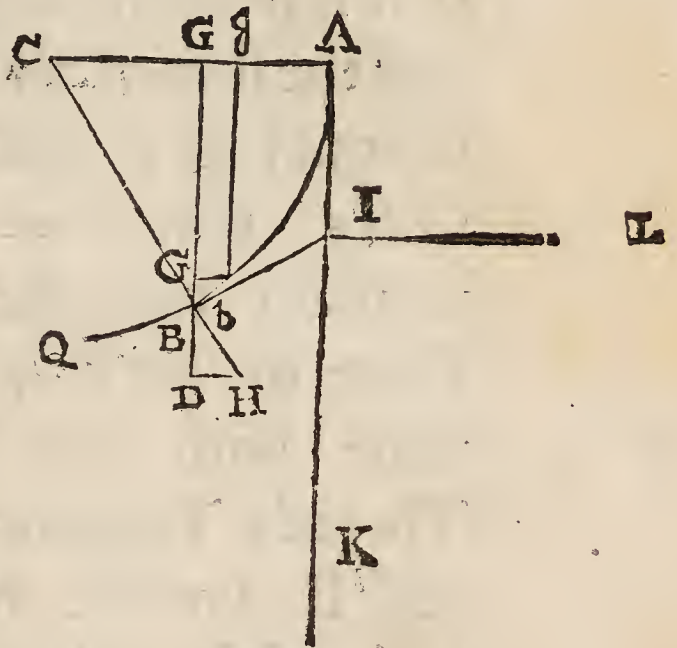
The Tension of the Fibre or the
 Force wherewith it is stretch'd by
 the Resistance Z may be thus de-
 termined. The Tension of the Fi-
 bre, or the Force sustaining the
 Weight in the Point B, is the same
 as if the Weight Z were suspend-
 ed by two Threads touching the
 Arches in the Point B, and in that
 Case the Tension of the Thread
 B F is to the Weight Z as the Sine
 of the Angle F B R or E B R is to
 the Sine of the Angle F B H or
 E B D

E B D (*a*) and consequently the Tension or Firmness of the Thread will be $= \frac{Z \times \text{Sine EBR}}{\text{Sine EBD}}$.

Now call the absolute force of Expansion that the Elastick Fluid must have to raise a given Weight to a determined Height *n*; the Pressure on any Part of the Thread will be as the Force of Expansion of the Fluid, and the Portion conjunctly; for if the Portions of the Thread be taken equal, the Pressures on them will be as the Force of Expansion, or the Elasticity, and if the Force of Expansion be the same, the Pressure is as the Portions on which it presses; and therefore universally it is as the Force of Expansion, and the Portion jointly, or as the Product of the two.

(*a*) By the 2^d cor. prop. 33 of the *Lectiões Physicæ* Jo Keil.

Let A B represent the circular Thread, B b an indefinite small Portion of the same, and the Pressure on B b will be $n \times B b$, which suppose equal to B H: The Pressure B H can be resolved into two Forces, one whereof is as D H

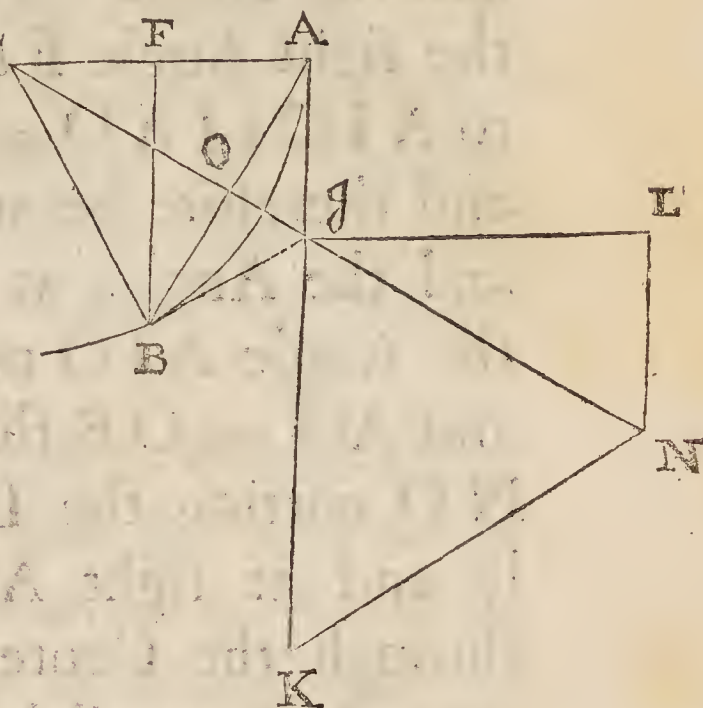


acting horizontally, or according to the Direction D H, and the other at B D acting vertically, or according to the vertical Direction B D, and because of the equiangular Triangles G B b and B D H. $B G : D H :: B b : B H :: B b : n \times B b$ ($:: 1 : n$) $:: G b : B D$, therefore $D H = n B G$, and $B D = n G b$, and therefore the sum of all

the horizontal Forces will be equal to n multiplied by all the $B G$'s, that is n multiplied by $B F = n \times B F$, and the sum of all the vertical Forces is equal to n multiplied by all the $G b$'s, that is $= n A F$. Now it is plain that the Tension of the Fibre in the Points A and B is the same with the Tension of two Threads Tangents in the Points A and B (where they are supposed to be fastened) that are drawn at their Point of Concourse I by all the horizontal Forces according to the Direction $I L$, and by all the vertical Forces according to the Direction $I K$: and therefore to determine the Tension of the Fibre, the Tension must be determined of the Threads that are pulled at the Point I by a Force $n F B$ according to the Direction $I L$, and by a Force $n F A$

n F A according to the Direction
I K. Take $IL = n F B$ and LN

perpendicular
to it $= n F A$,
and the two
Forces IL and
 LN will be e-
quipollent to a
third Force as
 IN acting ac-
cording to the
Direction IN ,
and therefore



the Threads will be stretch'd to the
same Degree by the Force IN that
they would be by the two Forces
 IL and LN , and because IL
 $(n B F) : LN (n F A) :: BF :$
 FA , and the Angles at L and F
equal (by the 6th of the 6th) the
Triangles BFA and ILN will be
equiangular, and the Side IN will
be

be equal to $n B A$, and the Angle $F A B = L N I = (\text{by } 29. 1) A I O$, add the Angle $I A O$ to both, and the right Angle $F A I$ will be equal to $A I O + I A O = (32. 1) A O C$; and therefore because $A I = I B$, and the Angles at A and B equal, the Angle $A I O$ must be $= B I O$ and $A O = O B$ the Line therefore $N O$ cutting the Line $A B$ equally and at right Angles must pass through the Center. Through N draw $N K$ parallel to $B I$, meeting with $A I$ produced in the Point K , then the Forces by which the Threads are stretched will be as $I K$ and $N K$, (*a*) the Angle $K I N = A I O = F A B = B I O = I N K$. The Triangle therefore $K I N$ is an Isosceles Triangle, and equiangular

(*a*) Keils *Lectiones Physicæ* prop. 33.

to the Triangle $A B C$, and $A B : A C :: N I : I K :: n A B : n A C$ and theretefore $I K$ or $K N$ will be equal to $n \times A C$, that is the Forces by which the Threads are stretch'd will be equal to the Radius of the Circle multiplied by n .

Hence the Tension of the Fibre in the Points A and B , and so in all other of its Parts, is the same and equal to the absolute Force of Elasticity multiplied into the Radius of the Circle. But the Tension of the Fibre was found before to be $\frac{Z \times \sin E B R}{\sin E B D}$, therefore if we call the Radius r . $nr = \frac{Z \times \sin E B R}{\sin E B D}$ and $n = \frac{Z \times \sin E B R}{r \times \sin E B D}$ and $r \times \sin E B D$ will have the same Proportion to the Sine $E B R$ as Z to n . Hence is plain that no finite Force of Elasticity can extend the Fibre $A E B D$

O

to

to a complete Circle, for in that case the Sine of the Angle $E B D$ being nothing $r \times \sin E B D$ is nothing, and therefore Z will be to n as nothing to something, or as a finite to an infinite.

The greatest Contraction of the Fibre that can be, must always be less than $\frac{72728}{100000}$ of such Parts whereof the Arch $A E$, is 100000, for if the Threads were extended into complete Circles, the Contraction would be only $\frac{72728}{100000}$ of $A E$, which it can never arrive to; therefore the Contraction must be always less than $\frac{1}{3}$ of the Length of the Fibre: It is also plain that when the Angle $E B R$ is small, the Force of Elasticity bears but a small Proportion to the Resistance. For Example when the Angle $E B R$ is but 30° the Radius or r multiplied
into

into the Sine of the Angle EBD the Sine of one Degree, is to the Sine of the Angle EBR the Sine of 30' as Z to n, that is, $r \times 1745 : 872 :: Z : n$, that is $Z : n :: 11459000 \times 1745 : 872 :: 19995955000 : 872 :: 22931141 : 1$, and consequently a small Degree of Elasticity will produce a prodigious Energy in the Muscles.

FINIS.

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